M1156 Precision Guidance Kit (PGK)

Initial Operational Test and Evaluation

March 2016

This report on the M1156 Precision Guidance Kit (PGK) fulfills the provisions of Title 10, United States Code, Section 2399. It assesses the adequacy of testing, the operational effectiveness, operational suitability, and survivability of the PGK.

J. Michael Gilmore
Director

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Executive Summary

This report provides my evaluation of the operational effectiveness, operational suitability, and survivability of the M1156 Precision Guidance Kit (PGK). PGK is operationally effective, operationally suitable, and survivable on the battlefield. Cannon artillery units equipped with PGK can effectively process and execute PGK fire missions using current fire support command, control, and communications systems. This assessment is based on data from the May 2015 Initial Operational Test and Evaluation (IOT&E) supplemented by data from the 2014 PGK Limited User Test (LUT), data from Lot Acceptance Tests (LATs), and appropriate modeling results. The IOT&E was adequate and executed in accordance with a test plan approved by the Director, Operational Test and Evaluation (DOT&E).

System Overview

PGK is a combined fuze and Global Positioning System (GPS) guidance module employed to improve the ballistic accuracy of the current stockpile of 155 millimeter (mm) high-explosive (HE) field artillery projectiles. Guidance is achieved during flight through the positioning of canards that control the flow of air around the projectile. In flight, PGK uses GPS position location information to adjust the position of the canards and flight path of the projectile towards its aimpoint.

Operational Effectiveness

PGK is operationally effective against targets serviced by field artillery units. PGK fuzes demonstrated sufficient accuracy and reliability to allow cannon artillery units to provide near-precision (less than 50 meters) accuracy when firing existing, unguided 155 mm HE projectiles in mid- and long-range mission fire scenarios. In IOT&E, 90 percent (18 of 20) of PGK missions fired were successful. PGK is capable of being fired from the M109A6 Paladin and the M777A2 Howitzer and is compatible with the two intended projectiles, the M795 HE projectile and the M549A1 HE Rocket-Assisted Projectile (RAP).

PGK is accurate. It demonstrated a circular error probable (CEP) of 13.0 meters during IOT&E and 10.0 meters when data from the lot acceptance testing are included with an upper 90 percent confidence bound of 20.9 meters. These results are better than the threshold and objective accuracy requirements of 50 and 30 meters, respectively. Further, PGK is more accurate than conventional HE projectiles at all ranges and PGK accuracy increases with range because of the longer time of flight in which guidance corrections can be made.

The lethality of M795 HE projectiles and M549A1 HE RAP, when fuzed with PGK, remains unchanged from the lethality of these projectiles when fuzed with conventional artillery fuzes. The employment of PGK fuzes on these projectiles improves achieved effects on the target by guiding each projectile closer to its intended target, thus making more efficient use of the projectile's current lethality.

PGK meets its reliability threshold requirement of 92 percent at a point estimate, but not with confidence (80 percent confidence interval of 89 – 95). When this demonstrated reliability is combined with the better-than-required accuracy, effectiveness modeling shows that against typical artillery targets, the PGK fuze provides damaging effects of at least 1.7 times the effects which would be achieved based on simply meeting the reliability and accuracy requirements. PGK, with a demonstrated upper bound on accuracy of 20.9 meters and a lower bound on reliability of 88.7 percent, produces lethal effects on target.

Operational Suitability

PGK fuze is operationally suitable. During IOT&E and three production LATs, testers fired 177 shots resulting in 14 failures, demonstrating a reliability point estimate of 92.1 percent with an 80 percent confidence interval of 88.7 – 94.6 percent. Six failure modes accounted for 11 of the 14 failures that occurred during the four tests. The key failure modes were: Loss of GPS Signal, Loss of Internal Power, and rounds that fall significantly short of their target (Short-Range Round). Failures of the capacitor in extreme cold environments (less than 0 degrees Fahrenheit) are fixed by changing the procedure to include a double-set of the fuze.

The PGK fuze is supportable within the Army's current maintenance, logistics, training, and manpower structures. With fielding of new Muzzle Velocity Management System and Digital Fire Control Systems (DFCS) on M777A2, the Army needs to provide adequate New Equipment Training (NET). The support strategy for PGK uses the standard Army two-level system of field and sustainment maintenance. PGKs are stored and maintained in sealed carrier bags in a standard ammunition container. Field maintenance consists of care, preservation, and cleaning of the PGK ammunition container. The PGK fuze is safe to store and transport in its ammunition containers. The Army should consider instituting a warning in Advanced Field Artillery Tactical Data System (AFATDS) for PGK restrictions and limitations.

Survivability

Limited PGK performance results in a GPS jammed environment are reported in a classified annex to this report. Laboratory testing to characterize performance in a GPS jammed environment will be conducted in fiscal year (FY) 2016.

Cybersecurity assessments identified vulnerabilities such that PGK may be susceptible to insider and nearsider cybersecurity threats with physical access. Cybersecurity testing and results are reported in a classified annex to this report. PGK has demonstrated in testing that PGK-fuzed projectiles are not more detectable in flight than conventionally-fuzed projectiles, so PGK does not increase the susceptibility of a field artillery unit to detection and counterfire.

Recommendations

The program manager for PGK should:

- Continue to conduct failure mode investigations for Dud, Loss of GPS Signal, and Loss of Internal Power failures and incorporate corrective actions to improve reliability.
- Continue to conduct failure mode investigations for Short-Range Round failures and incorporate corrective actions to improve reliability and safety.

- Update PGK tactics, techniques, and procedures (TTPs) to require Soldiers to double-set the PGK when operating in extreme cold environments (less than 0 degrees Fahrenheit) to ensure proper functioning of the fuze.
- Provide adequate NET on M777A2 with fielding of new Muzzle Velocity Management System and DFCS software to the Army.
- Consider changes in the DFCS and AFATDS to alert the operators of a violation of high quadrant elevation (QE) limitations when processing a PGK fire mission and to require an override to continue processing the mission.
- Address the identified cybersecurity vulnerabilities in the system-of-systems required to employ PGK per the classified cybersecurity annex.
- As discussed in the classified annex, perform a Cooperative Vulnerability and Penetration Assessment (CVPA) and an Adversarial Assessment (AA) on the complete Fire Support Architecture, including testing to evaluate the ability of the threat to control agents on compromised mission computers over the Single Channel Ground and Airborne Radio System (SINCGARS) network.

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Director

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Section One
System Overview

This report provides DOT&E's assessment of test adequacy, operational effectiveness, operational suitability, and survivability of the M1156 Precision Guidance Kit (PGK). This evaluation is based on data from the PGK Initial Operational Test and Evaluation (IOT&E) that the Army Test and Evaluation Command (ATEC) conducted in May 2015, in accordance with the DOT&E-approved test plan. IOT&E data are supplemented by data from the PGK Limited User Test (LUT) conducted by ATEC in January and February 2014, in accordance with a DOT&E-approved test plan, and by data from Lot Acceptance Tests (LATs) of low-rate initial production (LRIP) PGKs conducted between April and June 2015. A classified annex provides the cybersecurity assessment of PGK.

System Overview

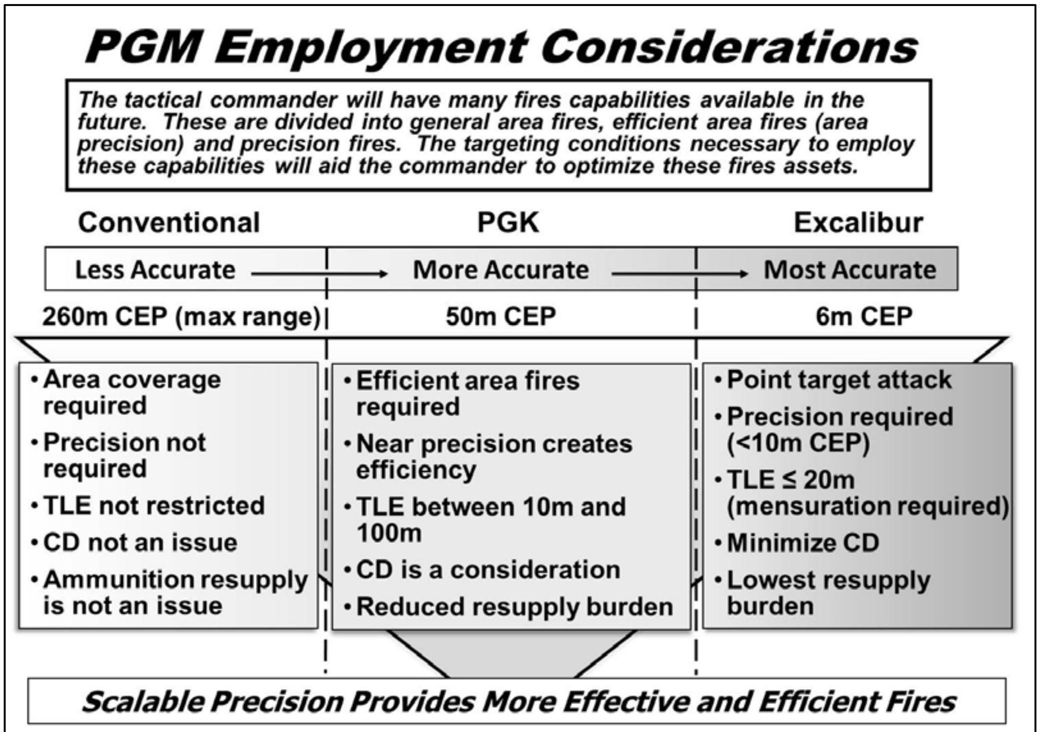
PGK is a combined fuze and Global Positioning System (GPS) guidance module used to improve the ballistic accuracy of the cannon-fired 155 millimeter (mm) high-explosive (HE) ammunition: the M795 HE projectile and the M549A1 HE, Rocket-Assisted Projectile (RAP). The Army developed PGK in two tracks:

- The first track focused on meeting an Army-directed requirement for fielding of PGK. The Army authorized Urgent Materiel Release (UMR) PGK fielding to deployed units supporting Operation Enduring Freedom on March 4, 2013. UMR PGK NA28 fuze production is complete.
- The second track is the Program of Record PGK NA29, which is focused on full-rate production (FRP).[1] The Army's Program Executive Officer for Ammunition approved PGK LRIP in March 2013. The Army plans to make a PGK FRP decision and achieve Initial Operational Capability (IOC) in the second quarter of fiscal year (FY) 2016.

Background

The Army is procuring two cannon-fired Precision-Guided Munitions (PGMs): the Excalibur Precision-Guided Projectile and PGK for employment with conventional HE projectiles. The Army is fielding both PGMs to satisfy a need for cannon-delivered projectiles that enable the maneuver commander to engage critical targets with increased accuracy, precision, range, and lethality while minimizing collateral damage in the target area. The Army combined the UMR PGK LUT and Excalibur Increment 1b IOT&E to demonstrate the complementary capabilities of both PGMs. Figure 1-1 identifies employment considerations for PGMs.

[1] The Program of Record PGK will be referred to in this report as PGK.

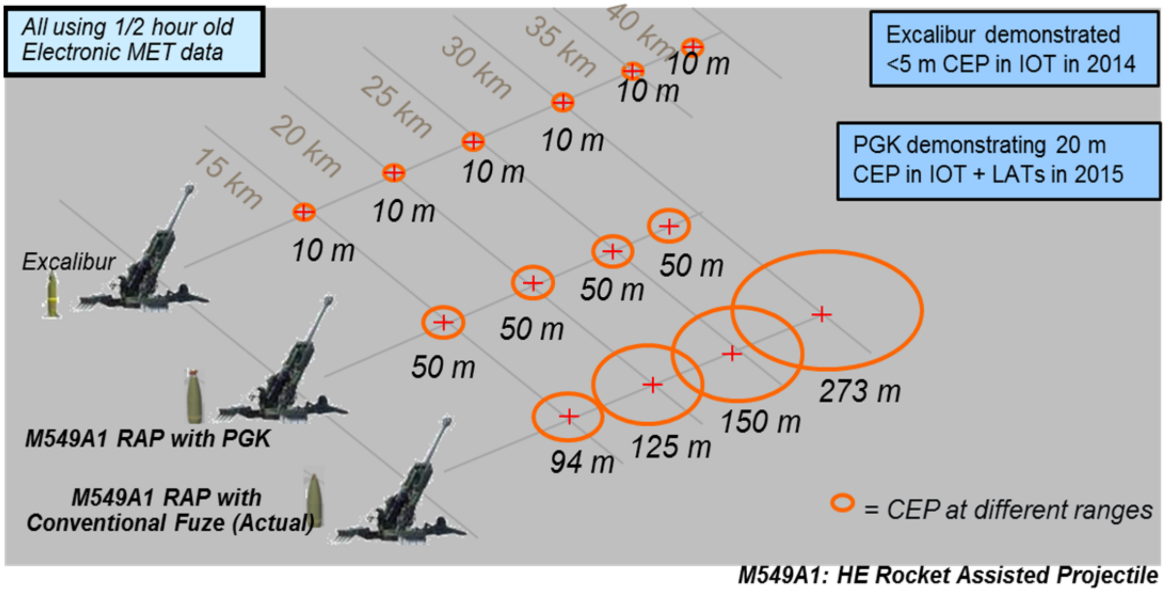


CEP – Circular Error Probable[2]; TLE – Target Location Error; CD – Collateral Damage

Figure 1-1. Precision-Guided Munition Employment Considerations

PGK provides field artillery units with a near-precision capability when employing current 155 mm HE projectiles with the PGK fuze. The lethality of the current 155 mm HE projectile with the addition of the PGK fuze delivers the standard HE projectile to near-precision (less than 50 meters CEP) accuracy. Near-precision accuracy provides greater lethal effects and less collateral damage over the current 155 mm HE projectile. Figure 1-2 provides a graphical comparison of accuracy at different ranges between demonstrated conventional fuze capabilities versus the Excalibur and PGK requirements. The numbers in the blue boxes present the actual Excalibur and PGK results demonstrated during testing.

[2] Circular Error Probable (CEP) is defined as the radius of a circle that contains 50 percent of the observed impacts. The median of observed RMDs is an estimate of CEP.



MET –Meteorological data; CEP – Circular Error Probable; HE – High-Explosive; RAP – Rocket-Assisted Projectile; LAT – Lot Acceptance Test

Figure 1-2. Relative Accuracy of PGMs and Conventional 155 mm Projectiles

Improved accuracy does not obviate the need for units firing Excalibur and PGK to adhere to the Five Requirements for Accurate Predicted Fire published by the Army's Fires Center of Excellence incorporated in the tactics, techniques, and procedures (TTPs) of individual munitions.

The Five Requirements for Accurate Predicted Fire, which artillery units need to ensure are satisfied, are:

- Accurate Target Location
- Accurate Firing Location
- Accurate Weapon and Ammunition Information
- Accurate Meteorological Information
- Accurate Computational Procedures

The effective delivery of fires requires a balance among accuracy, speed, and computational procedures.

System Description

PGK is a combined fuze and GPS guidance system employed to provide near-precision accuracy for the current stockpile of 155 mm HE field artillery projectiles. Guidance is achieved during flight through the positioning of canards that control the flow of air around the projectile. Figure 1-3 shows a PGK fuze and its protective canard cover.

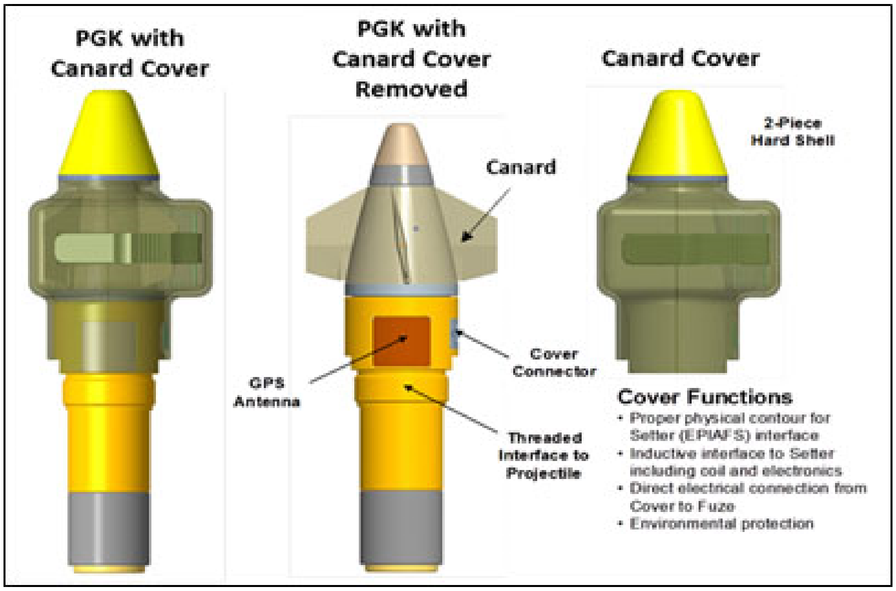


Figure 1-3. PGK with Canard Cover

In flight, PGK uses GPS position location information to adjust the position of the canards and flight path of the projectile toward its aimpoint. If a reliable PGK-fuzed projectile flies a guided trajectory and impacts within 150 meters of its aimpoint, it will detonate as either an airburst above the aimpoint (Height-of-Burst (HOB) fuze mode) or at the point of impact on the ground (Point Detonating (PD) fuze mode). The fuze mode is based on the desired effects on target and is provided to the fuze prior to firing.

Figure 1-4. Airburst of Two PGK-fuzed Projectiles above a Target

If the GPS signal is not acquired after firing or is lost during flight, the projectile will continue its flight on a ballistic trajectory and will impact as a dud, without detonation. If a PGK-fuzed projectile impacts outside 150 meters from its aimpoint, whether it has flown with or without guidance, it will impact as a dud. This design feature enables commanders to attack targets when it is important to minimize collateral damage.

Compatibility

PGK will be employed with:

- The M795 HE and M549A1HE RAP 155 mm projectiles
- Artillery firing platforms equipped with Digital Fire Control Systems (DFCS) and inductive fuze setters
  - M777A2 Lightweight Towed Howitzer
  - M109A6 Paladin Self-Propelled Howitzer
  - M109A7 Paladin Integrated Management (PIM) Howitzer
- U.S. bag propellant charges (M119A2 and M203A1) and the Modular Artillery Charge System (MACS) propellant charges (M231, M232, and M232A1)
- Artillery fire support mission-processing components, including fire support observer platforms and Advanced Field Artillery Tactical Data System (AFATDS)
- The GPS signal constellation environment

Key Requirements

PGK must demonstrate an accuracy that is less than or equal to 50 meters (threshold) and less than or equal to 30 meters (objective), circular error probable (CEP). Accuracy is measured with respect to the projectile's aimpoint in a non-countermeasured environment with 30-minute standard artillery meteorological data.

PGK reliability requirement is to achieve at least a threshold level of 92 percent reliability by its IOC in 2QFY16.

The threshold requirement for this increment of PGK is to have a Selected Availability Anti-Spoofing Module (SAASM) capability. There is not a written requirement for this increment of PGK to operate in a GPS jammed signal environment. The Army intends a follow-on increment of PGK to provide an anti-jam capability.

Mission Description and Concept of Employment

To fire a PGK-fuzed projectile, the unit Fire Direction Center (FDC) computes and transmits a digital firing solution to the howitzer section using AFATDS. The howitzer Section Chief then uses the DFCS on the firing platform to compute a PGK reference trajectory from the howitzer to the aimpoint. A cannoneer attaches the PGK with its protective canard cover to the projectile by hand and then tightens it using a PGK fuze wrench. The Enhanced Portable Inductive Artillery Fuze Setter (EPIAFS) sets the PGK by transferring the GPS key, fuze function mode, and reference trajectory data to the PGK. (See Figure 1-5.)

Figure 1-5. Enhanced Portable Inductive Artillery Fuze Setter (EPIAFS)

Once PGK is set, the canard cover is removed (Figure 1-6) and the projectile is fired (Figure 1-7).

Figure 1-6. PGKs (w/o Canard Covers) – Installed on M594A1 HE RAP (left) andM795 HE (right) 155 mm Projectiles

Figure 1-7. Firing from an M777A2 Howitzer

When fired, PGK acquires a GPS signal and receives GPS data throughout the flight to update the projectile's position. PGK then maneuvers the projectile along its reference trajectory toward its aimpoint. Should PGK fail to acquire a GPS signal or lose the signal during flight, PGK will not maneuver the projectile toward its aimpoint and the projectile will follow a ballistic trajectory to impact without detonation.

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Section Two
Test Adequacy

The Initial Operational Test and Evaluation (IOT&E) was executed in accordance with the DOT&E-approved test plan and was adequate to assess operational effectiveness, operational suitability, and survivability. This evaluation is based on the IOT&E and is supplemented by mission processing and timeline data from the 2014 Precision Guidance Kit (PGK) Limited User Test (LUT), data from Lot Acceptance Tests (LATs), select developmental tests on Electromagnetic Environmental Effects (E3), and appropriate modeling results. Cybersecurity testing consisted of a Cooperative Vulnerability and Penetration Assessment (CVPA) and an Adversarial Assessment (AA) conducted in conjunction with the IOT&E.

Operational Testing

The Army Test and Evaluation Command (ATEC) conducted the PGK IOT&E at Yuma Proving Ground (YPG), Arizona, in May 2015, and was the primary data source for this report. The 2014 LUT, conducted by ATEC at YPG on the Urgent Materiel Release (UMR) configuration of PGK in January and February 2014, was the source for Precision Guided Munition (PGM) mission processing and timeline data.

IOT&E

A howitzer platoon from C Battery, 2nd Battalion, 15th Field Artillery, 10th Mountain Division conducted the IOT&E with U.S. Marine Corps (USMC) M777A2 Howitzers available at YPG. These M777A2 Howitzers had the latest Digital Fire Control System (DFCS) software (version 4.1.0), which had been fielded to the Marines, but not to the Army. DFCS software version 4.1.0 has the latest NATO Artillery Ballistic Kernel and Fire Control Inputs for PGK.

The IOT&E consisted of vignettes involving tactical employment of a light howitzer unit in support of an infantry brigade combat team. A total of 48 PGK-equipped firings were planned in 24 missions (12 three-round platoon missions and 12 one-round missions). The Army structured the IOT&E as 2 vignettes of 12 missions each (24 PGKs). The 12 missions in the first vignette tested PGKs fuzed to M549A1 HE Rocket-Assisted Projectiles (RAP) and were conducted at three ranges – 22 kilometer (km), 23.5 km, and 25.5 km. The 12 missions in the second vignette tested PGKs fuzed to M795 HE projectiles and were fired at two ranges – 15 km and 19 km. Standard unguided HE missions were fired at each range.

In addition to range, the missions considered a balanced number of PGKs for each fuze mode – Point Detonating (PD) and Height-of-Burst (HOB). The remaining factor considered was quadrant elevation (QE) – low QE (less than 900 mils) and high QE (greater than or equal to 900 mils).[3] Four high QE missions were planned for each PGK-fuzed projectile type. The remaining eight firing missions for each PGK-fuzed projectile type were planned at low QE.

[3] Quadrant elevation (QE) is the angle between a howitzer tube in firing position and the horizontal plane. One mil equals 1/6400th of a circle. Nine hundred mils is 50.6 degrees elevation from the horizontal.

The Army conducted all firings in daylight conditions at ambient temperature with no temperature or environmental conditioning prior to the test.

The Army fired the 48 PGKs against representative threat targets (one target per mission) in a tactical oriented threat array simulating a threat airfield (see Figure 2-1). The conventional unguided HE missions were fired against representative threat targets (one target per mission) at similar ranges, but in a separate target array (see Figure 2-2).

Figure 2-1. PGK Target Array

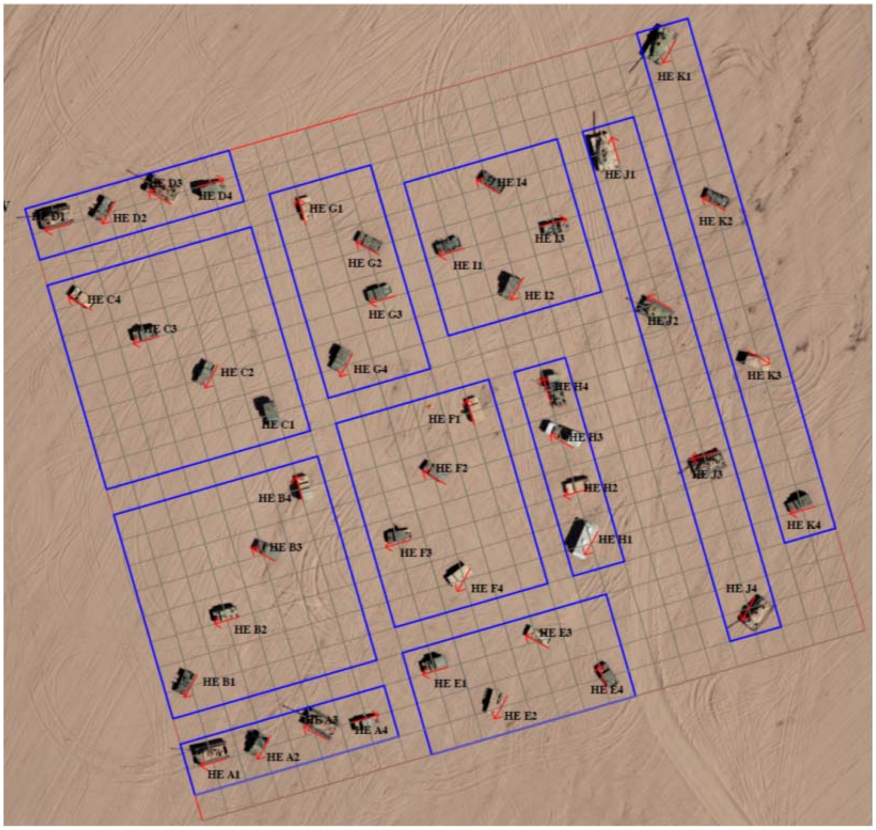

Figure 2-2. Conventional Unguided HE Target Array

As shown in Figure 2-3, the platoon received the fire mission from the test control cell manned by field artillery military personnel, representing a firing battery Fire Direction Center (FDC). The control cell received the intended target via a forward observer, a non-commissioned officer from ATEC, who generated the call-for-fire using predetermined target information.

The test platoon processed each IOT&E mission using the Advanced Field Artillery Tactical Data System (AFATDS) in their platoon FDC. The platoon FDC then sent the fire mission to three howitzers in the platoon for firing the three-round missions and to one howitzer for firing the one-round missions. Individual howitzers processed the fire mission on their DFCS, which computes the reference trajectory, sent appropriate fire mission data to the Enhanced Portable Inductive Artillery Fuze Setter (EPIAFS) for setting of PGK, and firing of the mission.

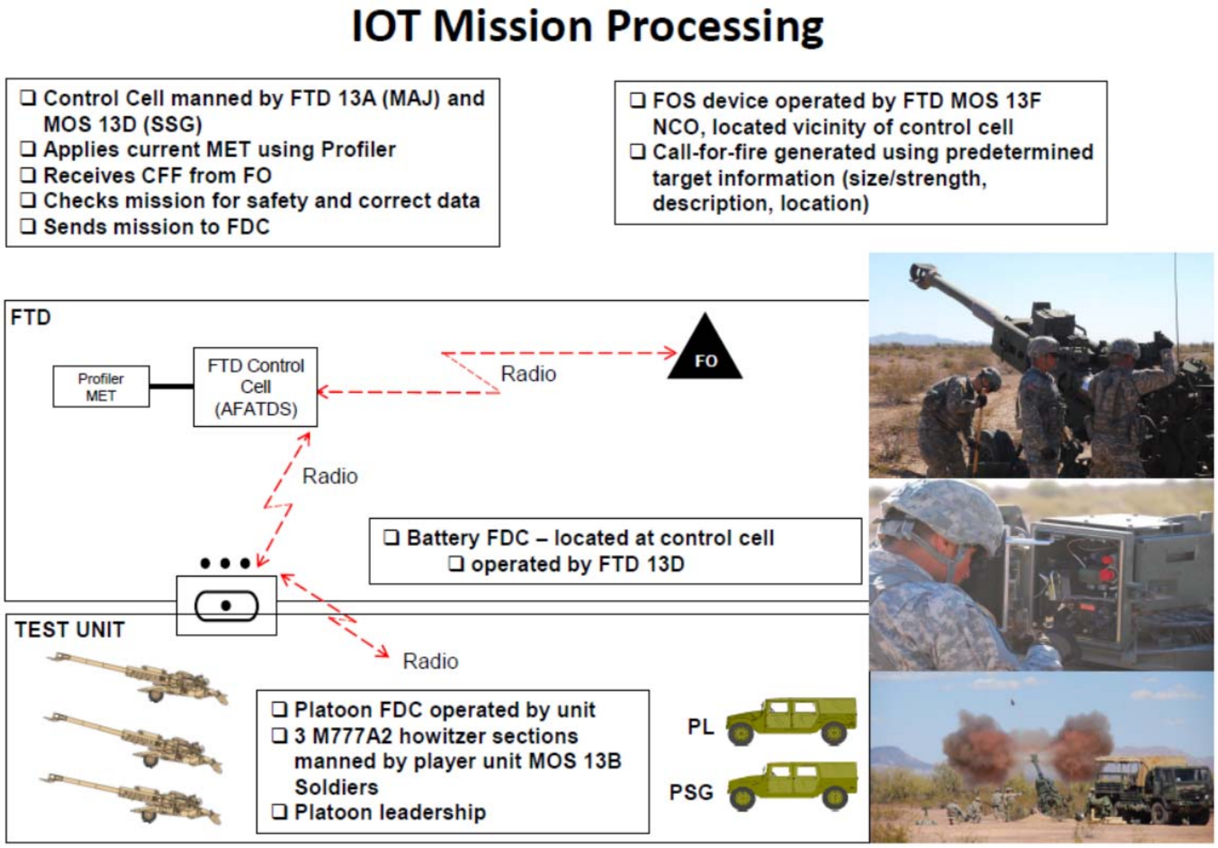

Figure 2-3. IOT&E Mission Processing Laydown

IOT&E Limitations

Four missions were not included in this analysis because three of the missions had improper firing solutions provided from AFATDS through the EPIAFS to the PGK-fuzed projectiles, and one mission was fired above the high QE limitation of PGK tactics, techniques, and procedures (TTPs):

- Insufficient crew training provided to the unit on the USMC DFCS software led to construction of improper firing solutions, which resulted in PGK-fuzed projectiles falling well short of their aimpoints for Missions 1 to 3. Firing was suspended following these missions. The crew identified the issue and executed subsequent missions. Missions 1 to 3 (five PGKs) are not included in the effectiveness or suitability analyses.

- Mission 7, the first high QE mission, was fired at a QE greater than the 936 mils QE limitation for M549A1 HE RAP in PGK TTPs. This was due to the target’s location relative to the howitzer’s firing position. This mission (one PGK) was not included in the effectiveness or suitability analyses.

- Subsequent attempts to fire the M549A1 HE RAP at high QE could not be fired since the QE was well above the 936 mil firing limitation. Data from the LATs were used for analyses of high QE firing conditions.

While these missed missions reduced the available data for the evaluation, the remaining data were adequate to evaluate the effectiveness, suitability, and survivability of PGK. The three missions with the improper firing solutions highlight the importance of the unit adhering to the Five Requirements for Accurate Fire published by the Army Fires Center of Excellence and the need to improve the New Equipment Training (NET) with the new DFCS version 4.1.0.

Limited User Test (LUT)[4]

ATEC conducted the LUT for the UMR PGK in January and February 2014 at YPG. ATEC conducted realistic operational testing of end-to-end PGK fire missions, from target acquisition, through command and control, to target area detonation. One of the focuses included the Precision-Guided Munition (PGM) mission processing in which the unit fired PGK, Excalibur Increment 1b, or conventional-fuzed HE projectiles based on the tactical situation.

The test unit's brigade combat observation lasing teams (COLTs) in M1200 Armored Knight vehicles and equipped with the Fire Support Sensor System (FS3) to locate targets occupied positions overlooking the target area. COLTs initiated call-for-fire requests for high-explosive (HE) and PGM projectiles using the Armored Knight's onboard Forward Observer System software.

The digital fire mission requests were processed using the AFATDS through the test unit's brigade Fire Support Element (FSE) and battalion Fire Direction Center (FDC). The FSE used test control cell-provided target information and graphics to conduct a hasty collateral damage estimate on the risk of causing civilian casualties using cannon-fired munitions. The FSE used the graphics and imagery, along with Commander's Guidance, the Attack Guidance Matrix, collateral damage considerations, and Rules of Engagement, to make its final munitions selection (conventional HE projectiles, PGK-fuzed projectiles, or Excalibur Increment 1b) for each LUT mission.

For missions firing conventionally-fuzed projectiles, the missions were processed through the battalion, battery, and platoon FDCs to the individual howitzers where the digital firing solutions were calculated and the projectiles were loaded and fired. For missions firing PGK-fuzed projectiles, the platoon FDC calculated the digital firing solutions for each howitzer and then controlled the timing of the setting of the PGK fuzes and the loading and firing of the projectile(s). Platoon level processing of PGK missions is described in more detail in the PGK Mission Timelines discussion in Section Three of this report.

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[4] For complete details on the test description and results of the LUT see DOT&E report, "Operational Assessment of the NA28 Precision Guidance Kit (PGK) Urgent Materiel Release (UMR) Variant," September 2014 and "M982E1 Excalibur Increment 1B Combined Initial Operational Test and Evaluation and Live Fire Test and Evaluation Report," June 2014.

Supplemental Testing

Developmental Testing

PGK contractor and Government developmental testing focused on projectile and system-level safety, performance qualification, reliability growth, and performance qualification. The developmental test results used for this evaluation are the non-firing tests for E3 and the nuclear, biological, and chemical (NBC) contamination and decontamination susceptibility analysis.

Lot Acceptance Testing (LAT)

The program manager began low-rate initial production (LRIP) in December 2014. The program will produce a total of 4,776 PGKs in 9 lots.[5] The LATs for the LRIP lots began with Lot 1 (282 fuzes) at the end of April 2015. The LAT for Lot 2 (366 fuzes) was at the end of May 2015. The LAT for Lot 3 (528 fuzes) was at the end of June 2015. Since the 48 IOT&E fuzes were selected from production Lot 1 and all 3 lots were produced with the same configuration, both accuracy and reliability data from the LATs were included in the analysis for this evaluation.

The program manager prepared a total of 135 PGKs for the three LATs, 42 each for LATs 1 and 2 and 51 for LAT 3. An additional nine PGKs were added to LAT 3 to make up for data lost during IOT&E. For the LATs, a minimum of 12 and a maximum of 40 PGKs are needed to accept or reject the lot production depending upon PGK performance. A total of 94 of the 135 PGKs (42 in LAT 1, and 26 in each of LAT 2 and LAT 3) underwent Paladin Tactical Vibration conditioning which also subjected the fuzes to conditioning at extreme temperature, one-half at -25 degrees Fahrenheit and one-half at +145 degrees Fahrenheit. A total of 72 PGKs, evenly split between cold and hot temperature conditioning at the time of firing, were required to accept the three lots. The remaining 63 PGKs were fired in ambient conditions to augment the developmental test data available for the accuracy and reliability analyses in this evaluation.

Cybersecurity Testing

In March 2015, the Army conducted a CVPA of the PGK fuze and the M777A2 Howitzer. This assessment is a cooperative examination of the system to identify cybersecurity vulnerabilities and the risk of exploitation of those vulnerabilities.

During the IOT&E, the Army conducted an AA to determine the ability of a unit equipped with PGK to protect, defend, recover, and restore effective unit operations while withstanding validated and representative cybersecurity threat activity.

Cybersecurity testing and results are reported in a classified annex to this report.

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[5] The total planned production of PGKs is 102,000 fuzes for the Army and Marines.

Section Three
Operational Effectiveness

The Precision Guidance Kit (PGK) fuze is operationally effective. Cannon artillery units equipped with PGK can process and execute PGK fire missions using current fire support command, control, and communications systems. PGK provides near-precision accuracy (median radial miss distance (RMD) of 10.0 meters) and allows artillery units to achieve desired effects on targets using fewer projectiles than would be required to achieve similar effects with standard, unguided 155 millimeter (mm) high-explosive (HE) projectiles in the mid-range and long-range mission scenarios.[6] Using fewer projectiles with increased accuracy allows artillery units to attack more targets in areas where collateral damage is a concern.

Mission Accomplishment

In the Initial Operational Test and Evaluation (IOT&E), 18 of 20 PGK missions fired were successful. A successful mission is defined as a mission in which at least one PGK-fuzed projectile would have produced damaging effects on the intended target. For the M549A1 Rocket-Assisted Projectiles (RAP) in Vignette 1, six of eight missions were successful. For the M795 HE projectiles in Vignette 2, all 12 missions were successful.

Tables 3-1 and 3-2 show operational mission success by vignette and mission for the IOT&E. These tables include the firing parameters (gun-to-target range, number of PGK-fuzed projectiles, quadrant elevation (QE) and fuze mode) associated with each mission during the two vignettes.[7] RMD is shown for individual PGK-fuzed projectiles. The last column of each table includes an assessment, by mission, of whether the mission was a success. The radius of effects of the Army's legacy 155 mm HE projectiles, approximately 50 meters, does not change with the use of PGK.

The probability that a single PGK-fuzed projectile produces damaging effects on an intended target is the probability that the RMD is less than or equal to 50 meters multiplied by the PGK reliability. For this assessment, a total of 94.0 percent of the observed RMDs from IOT&E and Lot Acceptance Testing (LAT) were less than or equal to 50 meters. This estimate, coupled with the demonstrated point estimate of PGK reliability of 92.1 percent, yields a likelihood of mission success of 86.6 percent.

Table 3-1 summarizes PGK-fuzed M549A1 RAP data collected in Vignette 1. The table indicates that the first three PGK missions in Vignette 1 were not included in the analysis. As was discussed in the test adequacy section of this report, the unit had not been properly trained on the USMC version of the Digital Fire Control System (DFCS) software. Insufficient crew training provided to the unit on the USMC DFCS software led to processing of improper fire mission data. Howitzers process fire missions on their DFCS, which computes the reference trajectory, and sends the fire mission data to EPIAFS for setting the PGK. These PGK-fuzed

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6 Demonstrated in FCOE studies and in ATEC LUT report – July 2014.

7 PGK has two fuze modes – Point Detonating (PD) and Height-of-Burst (HOB).

projectiles, as well as the conventional-fuzed HE projectiles fired prior to the first PGK mission, impacted well short of their intended targets.

One additional PGK mission in Vignette 1 was not included in the analysis. The unit did not fire Mission 7 in accordance with established PGK tactics, techniques, and procedures (TTPs). Due to the target's location relative to the howitzer's firing position, Mission 7 was fired at a QE greater than the 936 mil QE firing limitation for M549A1 HE RAP. PGK-fuzed projectile impacted short of its intended target.

For the M549A1 RAP in Vignette 1, six of eight missions were successful. The five PGK reliability failures identified in Table 3-1 will be discussed in Section Four of this report.

Table 3-1. Vignette 1 – M549A1 155 mm HE RAP

Operational Mission Success

IOT Effectiveness

Vignette 1 – M549A1 155mm HE RAP Projectile

Failure

PGK Mission Number	Target	Range (Km)	Number Of PGKs	Quadrant Elevation	Fuze Mode	Radial Miss Distances (m) (Accuracy)			Reliable Function	Mission Success* (Effects on Target)
1	Fuel Truck	25.5	1	Low	PD	First 3 PGK mission (5 PGKs) had improper firing solutions – not caused by PGK.				
2	D-30 Howitzer	25.5	3	Low	PD					
3	HMMWV	25.5	1	Low	HOB					
4	Helicopter	25.5	3	Low	HOB	5.7	7.4	3.6	3/3	Yes
5	Fuel Tank	22.0	1	Low	PD	2.7			1/1	Yes
6	Air Traffic Control Tower	22.0	3	Low	PD	8.9	5.3	12.4	3/3	Yes
7	SA9 Vehicle	22.0	1	High	PD	Single PGK fired at high QE beyond limit of TTPs				
8	Flagpole	22.0	1	Low	HOB	3.2			1/1	Yes
9	Track Radar	22.0	3	Low	HOB	14.7	2.8	4.7	3/3	Yes
10	West Hanger	23.5	1	Low	PD	93.8 (GPS Drop Lock)			0/1	No
11	Commo Tower	23.5	3	Low	PD	124.3	110.4. (Dud)	182 (Dud)	1/3	No
12	Wind Sock	23.5	3	Low	HOB	60.4 (Dud)	40.8	63.5 (GPS Drop Lock)	1/3	Yes

* Mission Success = Accuracy + Reliability => Effects on Target

** Mission success compromised by unit mishandling muzzle velocities on new howitzers unit used at YPG.

*** Mission fired at quadrant elevation higher than Tactics, Techniques, and Procedures stated limitation.

Planned = 24
Other = 6
Failures = 5
Successes = 13

Table 3-2 summarizes PGK-fuzed M795 data collected in Vignette 2. For the M795 HE projectiles in Vignette 2, all 12 missions were successful.

In the IOT&E, 18 of the 20 PGK missions fired were successful, yielding a simple estimate of Mission Success of 90 percent with an 80 percent confidence interval of 75 – 97 percent. This rate is consistent with the estimated 86.6 percent overall likelihood of mission success rate discussed above.

Table 3-2. Vignette 2 – M795 155 mm HE Projectile

Operational Mission Success

IOT Effectiveness

Vignette 2 – M795 155mm HE Projectile

Mission Number	Target	Range (Km)	Number Of PGKs	Quadrant Elevation	Fuze Mode	Radial Miss Distances (m) (Accuracy)			Reliable Function	Mission Success (Effects on Target)
1	Guardpost West	15.0	1	High	HOB	9.6			1/1	Yes
2	East Guard Tower	15.0	3	High	HOB	63.5	20.8	113.4	3/3	Yes
3	HMMWV	15.0	1	Low	HOB	26.1			1/1	Yes
4	West Guard Tower	15.0	3	Low	HOB	11.2	13.4	35.2	3/3	Yes
5	East Hanger	15.0	1	Low	PD	16.3			1/1	Yes
6	Track Rocket Truck	15.0	3	Low	PD	36.1	39.2	63.0	3/3	Yes
7	Center Connex	15.0	1	High	PD	7.8			1/1	Yes
8	Track Tank	15.0	3	High	PD	7.3	6.2	75.0	3/3	Yes
9	Bunker	19.0	1	Low	PD	16.4			1/1	Yes
10	A-4 Jet	19.0	3	Low	PD	10.2	8.5	17.5	3/3	Yes
11	West Hanger	19.0	1	Low	HOB	13.4			1/1	Yes
12	Helicopter	19.0	3	Low	HOB	2.3	13.0	12.4	3/3	Yes

Planned = 24
Successes = 24

* Mission Success = Accuracy + Reliability => Effects on Target

PGK Performance

The ability of cannon artillery units equipped with PGK to accomplish their mission is a function of four primary factors: PGK compatibility with other components of the artillery fire support system, the accuracy of PGK-fuzed projectiles, the reliability of the PGK fuze, and the lethality of existing 155 mm HE projectiles.

Compatibility

In developmental and operational testing, the Army fired PGK with M795 HE and M549A1 HE RAP and Modular Artillery Charge System (MACS) propellant (Figure 3-1) from the Paladin M109A6 and the M777A2 Howitzers (Figure 3-2) with no compatibility issues identified.

PGK demonstrated compatibility with multiple types of Howitzers. Soldiers from the 1st Infantry Division equipped with M109A6 Paladin Self-Propelled Howitzers executed the PGK Limited User Test (LUT) with Urgent Materiel Release (UMR) configuration PGK fuzes with no compatibility issues. During the IOT&E, Soldiers from the 10th Mountain Division unit equipped with M777A2 USMC Howitzers fired PGK. The Army conducted limited firing of

PGK with the U.S. Paladin Integration Management (PIM) and the German Pzh 2000 Self-Propelled Howitzers with no compatibility issues identified.

Figure 3-1. M549A1 HE RAP with PGK (left), M795 HE Projectile (center), and MACS Propellant (right)

Figure 3-2. Paladin M109A6 (left) and M777A2 Howitzers (right)

PGK uses Global Positioning System (GPS) data to achieve near-precision accuracy. During flight, as long as PGK maintains its connectivity with the GPS satellites, PGK continues to maneuver the projectile to the target. PGK has demonstrated compatibility with GPS in over 1,300 developmental and operational test firings.

PGK is compatible with the DFCS found in field artillery units. The systems include:

- Forward Observer System – provides the observer's target information;
- AFATDS – transmits tactical and technical fire mission information to the firing platform;
- EPIAFS – loads fire mission and target information into the PGK.

Accuracy

For the combined IOT&E and LAT, the demonstrated median radial miss distance (RMD) was 10.0 meters with an upper, one-sided 90 percent confidence bound on CEP of 20.9 meters, well below both the threshold (50 meters) and objective (30 meters) accuracy requirements. Accuracy is measured with respect to the projectile's aimpoint in a non-countermeasured environment with 30-minute standard artillery meteorological data.

Accuracy data were collected during the PGK IOT&E and three LATs. Accuracy analyses are presented for the IOT&E data and then for the combined IOT&E and LAT data.

IOT&E Accuracy

The overall median RMD for the 39 PGKs considered was 13.0 meters, well below the 50 meter requirement. The median RMD for the 15 PGK-fuzed M549A1 HE RAP was, overall, 50 percent lower (7.4 meters) than the median RMD for the 24 PGK-fuzed M795 HE projectiles (14.8 meters).[8] The lower RMD for the M549A1 HE RAP was due to the longer ranges at which IOT&E targets were engaged. Longer gun-to-target distances mean longer time of flight and more time for PGK to correct the flight trajectory to the aimpoint. Table 3-3 summarizes IOT&E RMD data.

Table 3-3. Summary of Observed Radial Miss Distances by Projectile Type and Range

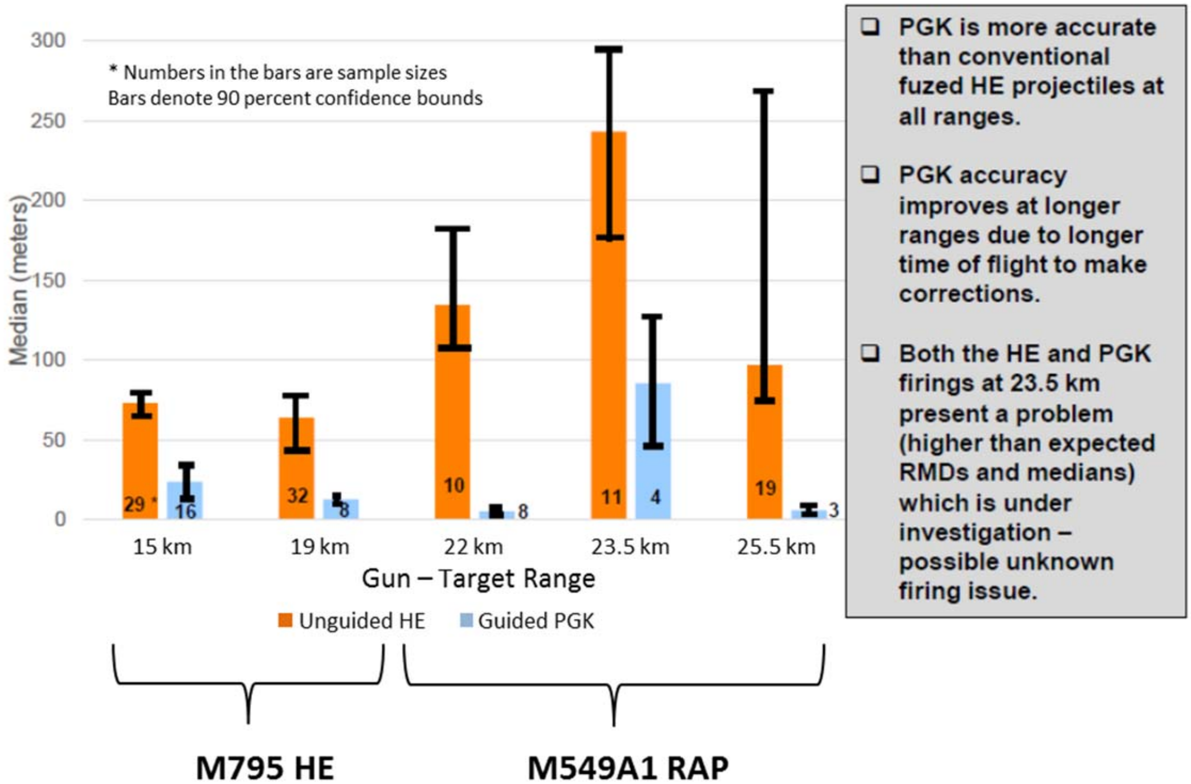
Vignette	Projectile	Range	Rounds Fired*	Radial Miss Distance (m)			
				Median	Mean	Minimum	Maximum
1	M549A1 RAP	22 km	8	5.0	6.8	2.7	14.7
		23.5 km	4	85.4	84.0	40.8	124.3
		25.5 km	3	5.7	5.6	3.6	7.4
Total – M549A1 RAP			15	7.4	27.1	2.7	124.3
2	M795 HE	15 km	16	23.5	34.0	6.2	113.4
		19 km	8	12.7	11.7	2.3	17.5
Total – M795 HE			24	14.8	26.6	2.3	113.4
Combined			39	13.0	26.8	2.3	124.3

HE – High-Explosive; RAP – Rocket-Assisted Projectile
* Rounds fired in the IOT&E that are included in accuracy computation – excludes six rounds and three reliability failures not considered in the analysis.

Four of the projectiles fired during IOT&E were anomalous. The median RMD for these four PGK-fuzed projectiles was 85.4 meters. This median RMD is over 13 times larger than the median M549A1 RMD observed in LATs (6.0 meters).[9] All projectiles fired at this range (23.5 km) were fired at low QE to replace firing data lost from improper firing solutions in the initial PGK missions at the beginning of Vignette 1. Further discussion of this phenomenon is presented following Figure 3-3.

[8] P-value = 0.094, based on a Mood's Median test.

[9] P-value = 0.001, based on a Mood's Median test.



HE – High-Explosive; RAP – Rocket-Assisted Projectile; RMD – Radial Miss Distance

Figure 3-3. PGK and HE Observed Median Measures

As demonstrated in Figure 3-3, both the conventionally-fuzed projectiles and the PGK-fuzed projectiles fired from the 23.5 km firing position had large median RMDs not consistent with the rest of the data. It is evident that there was a systematic error in the execution of both conventional and PGK firings from this firing position. Whether it was inaccurate firing location data, inaccurate weapon or ammunition information, or improper computational procedures; one of the Five Requirements for Accurate Predicted Fire was not met in the execution of these missions. If the four PGK-fuzed projectiles fired from the 23.5 km firing position are excluded, the remaining 11 M549A1 RAP firings in Table 3-3 have a median RMD of 5.3 meters and the remaining 35 IOT&E firings (11 M549A1 RAPs and 24 M795 HEs) have an overall median RMD of 12.4 meters.

PGK IOT&E included the firing of over 100 conventionally-fuzed M795 HE and M549A1 RAP projectiles. Figure 3-3 shows the observed median RMDs, by range, for the conventionally-fuzed projectiles compared to the PGK-fuzed projectiles. The PGK-fuzed projectiles, with an overall median RMD of 13.0 meters, are over 6 times more accurate than the conventionally-fuzed projectiles, with an overall median RMD of 85.0 meters.[10]

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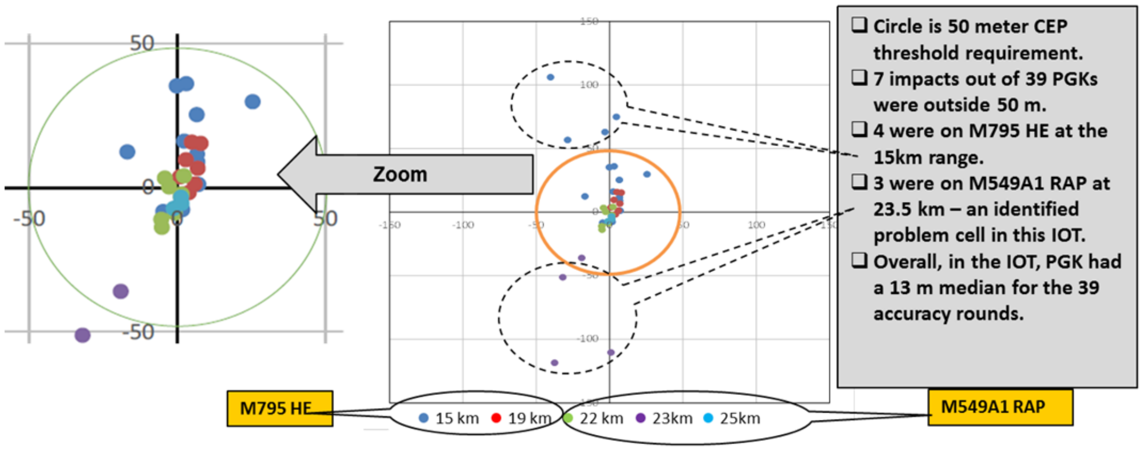
10 P-value = 0.0001, based on a Mood's median test.

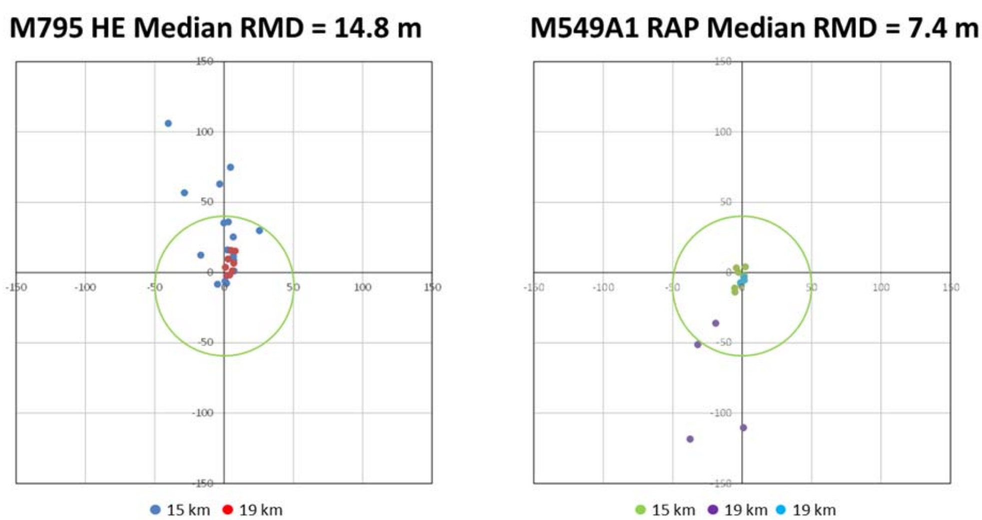
Figure 3-4 shows that all but 7 of the 39 PGK-equipped IOT&E impacts were within 50 meters of the aimpoint. Of these seven impacts, four were the result of PGK-fuzed projectiles fired at 15 km, the shortest range fired in the IOT&E. The shorter range means a shorter time of flight, with less time for PGK to maneuver the projectile to the aimpoint prior to impact. The remaining three impacts that hit greater than 50 meters off target occurred in the group of M549A1 RAP fired from the 23.5 km firing position.



CEP – Circular Error Probable; HE – High-Explosive; RAP – Rocket-Assisted Projectile

Figure 3-4. Impact Points Relative to Aimpoint in IOT&E

Figure 3-5 shows the individual impact locations, relative to the aimpoint, for each of the IOT&E PGK firings by projectile type and range. 20 of 24 PGK-fuzed M795 HE projectiles impacted within 50 meters of their respective aimpoints, and the overall median RMD of the M795 HE PGK-fuzed projectiles was 14.8 meters. 12 of 15 PGK-fuzed M549A1 RAP projectiles impacted within 50 meters of their respective aimpoints, and the overall median RMD for the M549A1 RAP PGK-fuzed projectiles was 7.4 meters. Using the median RMD as the estimate for CEP, both munitions achieved accuracy within the 50-meter CEP requirement.



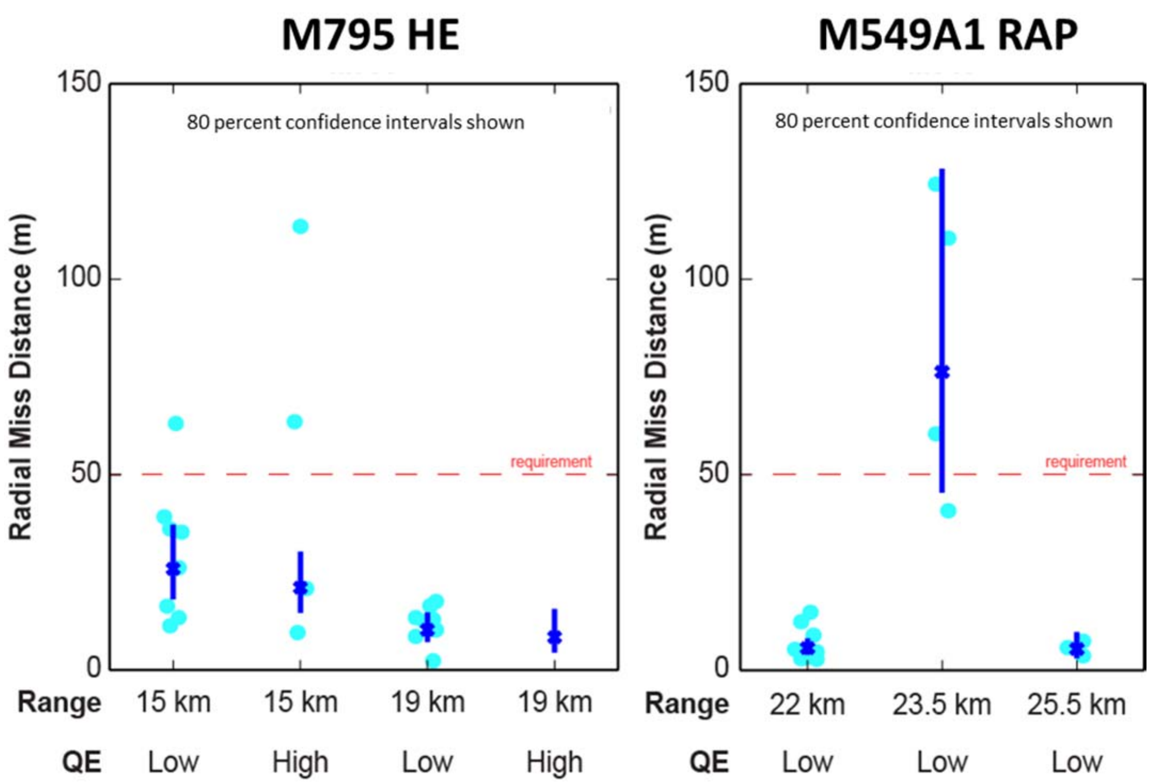
HE – High Explosive; RAP – Rocket-Assisted Projectile

Figure 3-5. IOT&E RMDs by Projectile Type and Range

DOT&E analyzed the RMDs for each of the PGK-fuzed projectiles fired in the IOT&E to determine the effects of range, QE, and fuze mode. Figure 3-6 shows the results of the regression modeling for the RMDs.

For the M795 HE projectile, QE and fuze mode were not significant factors.[11] Range was found to be a significant factor contributing to the RMDs observed in the IOT&E.[12] The Army fired the M795 HE projectiles at two ranges – 15 km and 19 km. The RMDs were higher at the shorter 15 km range than for the 19 km range. At the 15 km range, the shorter flight time and reduced maneuver time of the PGK-fuzed M795 are known to contribute to reduced accuracy.

For the M549A1 HE RAP, there were no high QE data available. DOT&E did not examine the planned factor of QE. Fuze mode was found to be not significant.[13] Given the anomalous data at the 23.5 km range, it could not be determined if RMD decreased with range.



HE – High-Explosive; RAP – Rocket-Assisted Projectile; QE – Quadrant Elevation

Figure 3-6. Parametric Survival Model with QE and Range Factors for IOT&E

IOT&E and Lot Acceptance Test (LAT) Accuracy

Each PGK LAT is a sequential test with 42 PGKs available for testing. Acceptance of the lot can be accomplished using as few as 12 PGKs. In support of reliability testing, the

11 P-value = 0.61 and 0.99

12 P-value = 0.03

13 P-value = 0.14

program manager fired all 42 PGKs for each of the three lots. An additional nine firings were added during LAT for Lot 3 to make up for data lost during IOT&E. Inclusion of the LAT data in the analysis provides additional insight into the accuracy assessment of PGK. LAT increases the available data from 39 to 167 PGKs for the accuracy assessment.[14]

For the 167 PGKs in the combined LATs and IOT&E, the demonstrated median RMD was 10.0 meters with an upper one-sided 90 percent confidence bound on CEP of 20.9 meters, well below both the threshold and objective accuracy requirements of 50 and 30 meters, respectively.

Table 3-4 provides a summary of the accuracy estimates for each of the four tests. The observed median for the LAT 1 sample was the smallest median at 6.0 meters. The LAT 1 data had the least variability in RMDs as reflected by the upper one-sided 90 percent confidence bound on CEP of 8.0 meters. Of the 41 PGKs in LAT 1 used in this analysis, 36 impacts were 10 meters or less from the aimpoint. The IOT&E, with an observed median of 13.0 meters, had the largest variability in RMDs as reflected by the upper one-sided 90 percent confidence bound on CEP of 34.0 meters.

The PGK-fuzed projectiles fired in LAT 1 were significantly more accurate than those fired in the other three test events.[15] Why LAT 1 accuracy performance was better is unknown. The PGK fuzes tested in the four test events were of the same production configuration and all LATs were conducted at the same test site and under the same testing procedures. Varying meteorological conditions under which the test firings were executed may have been a factor. Meteorological conditions, which change day-to-day and often hour-to-hour, are known to affect artillery accuracy. LAT 1 was conducted between April 21 – 23, 2015, while the other three tests were conducted on six additional firing days between May 6 and June 24, 2015. In the absence of a known explanation for LAT 1's accuracy relative to the other test events, LAT 1 data were included in our overall accuracy assessment since it does represent an actual test outcome. As shown in Table 3-4, our estimate of PGK's overall accuracy is 10 meters CEP. If LAT 1 data were excluded, the estimate would be 12 meters CEP.

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14 Not all 135 shots could be used for the accuracy analysis, 7 of the PGK fuzes failed to guide.

15 A parametric survival model was fit to the RMD data using test event (IOT&E, LAT 1, LAT 2, and LAT 3) as a factor. A hypothesis test of the equality of the median RMDs of the tests showed that the observed RMD of LAT 1 is statistically different than the RMDs of the other tests (p-value = 0.001).

Table 3-4. Summary of PGK Accuracy Results by Test Event

Test	Sample Size	Observed Median (m)	Analytical Estimate of CEP (m)	Upper One-Sided 90% Confidence Bound (m)
IOT&E	39	13.0	30.2	34.0
LAT 1	41	6.0	7.2	8.0
LAT 2	38	10.5	14.4	16.1
LAT 3 & Plus Ups	49	13.0	19.6	21.8
Current Estimate	167	10.0	19.9	20.9

IOT&E – Initial Operational Test and Evaluation; LAT – Lot Acceptance Test; CEP – Circular Error Probable

Included in Table 3-4 is an analytical estimate of CEP and an upper one-sided 90 percent confidence bound on the CEP estimate.[16] In contrast to the observed median RMD estimate of the CEP, in which all RMDs larger and smaller than the median are weighted in the estimate, the analytic estimate of the CEP accounts for the actual spread of the RMDs about the median.

DOT&E analyzed the combined IOT&E and LAT data for each projectile type so that the significance of range, QE, and fuze mode could be determined.[17] Figure 3-7 shows the results of the regression modeling for the RMDs. Eighty percent confidence bands on the predicted median RMD as the range varies are shown for each projectile type.

For the M795 HE projectile, range was found to be a significant factor with RMD improving with increasing range.[18] The capability of PGK to maneuver the projectile toward the aimpoint improves with longer flight times over the range tested of 14.8 to 20.9 km. Overall, 87 of the 92 (95 percent) RMDs were less than the 50-meter CEP requirement. Four of the five shots with RMDs exceeding 50 meters were fired in the IOT&E at the 15 km range. QE and fuze mode were not significant factors in predicting the median RMD.[19]

For the M549A1 HE RAP, none of the three factors (range, QE, and fuze mode) were significant in predicting the median RMD.[20] PGK-fuzed M549A1 HE RAP projectiles were fired at ranges from 20.2 to 27.3 km. The model's confidence band shows that the fitted RMDs for this projectile are constant over the range band from 20 to 27 km. Overall, 70 of the 75 (93 percent) RMDs were less than the 50-meter CEP requirement.

16 The method used to develop this analytical estimate was the Mixture of Non-Central Chi-Squared Approximation (referred to as "Mixture Method"). This method was developed by the Army Materiel Systems Analysis Activity in conjunction with AEC. It uses an approximation method found in the textbook titled "Statistical Tolerance Regions: Theory, Applications, and Computation" by K. Krishnamoorthy and Thomas Matthew.

17 Data were analyzed with a Parametric Survival Model.

18 P-value = 0.007

19 P-values = 0.65 and 0.64

20 P-values = 0.96, 0.44, and 0.85

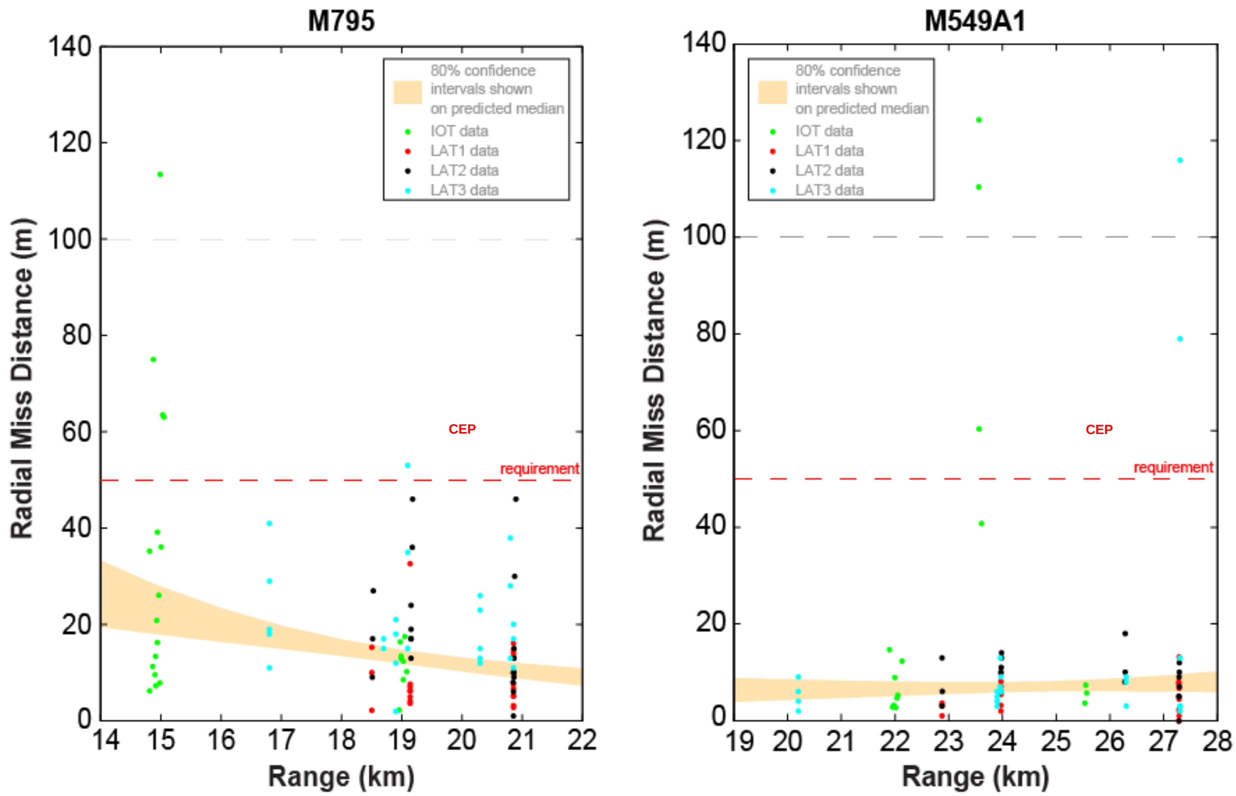


Figure 3-7. Parametric Survival Model with Range Factor for IOT&E and LATs

Reliability

In the IOT&E and the three LATs supporting this assessment, PGK met its threshold requirement of 92 percent reliability at a point estimate (demonstrated 92.1 percent), but not with confidence. The lower bound of the 80 percent confidence interval for reliability is 88.7 percent. The PGK reliability requirement is to achieve at least a threshold level of 92 percent reliability by its Initial Operational Capability (IOC), scheduled for 2QFY16.

A summary of PGK reliability and how it affects operational effectiveness is presented in a subsequent paragraph of this section.

A summary of PGK reliability by test event, including reliability failure modes and their impact on operational suitability, is presented in Section Four of this report.

Lethality

The final factor in PGK's contribution to more effective and efficient artillery fires is the lethality of the current 155 mm HE projectiles – the M795 HE projectile and the M549A1 HE RAP. The lethality of these munitions when fuzed with a PGK remains unchanged from their lethality when fuzed with conventional artillery fuzes. The lethality of PGK-fuzed projectiles was seen by considerable damage to multiple target types engaged from varying operational ranges throughout PGK's IOT&E.

Figure 3-8 shows before-and-after photos of a helicopter target in Vignette 1 – Mission 4. This mission was a three-round volley of M549A1 HE RAP at 25.5 km in HOB-fuze mode. The RMDs for the three rounds were 5.7 meters, 7.4 meters, and 3.6 meters.

Figure 3-8. Vignette 1 – Mission 4

Figure 3-9 shows before-and-after photos of an air traffic control tower target in Vignette 1 – Mission 6. This mission was a three-round volley of M549A1 HE RAP at 22 km in PD-fuze mode. The RMDs for the three rounds were 8.9 meters, 5.3 meters, and 12.4 meters.

Figure 3-9. Vignette 1 – Mission 6

Figure 3-10 shows before-and-after photos of an A-4 jet target in Vignette 2 – Mission 10. This mission was a three-round volley of M795 HE projectiles at 19 km in PD-fuze mode. The RMDs for the three rounds were 10.2 meters, 8.5 meters, and 17.5 meters.

Figure 3-10. Vignette 2 – Mission 10

Figure 3-11 shows before-and-after photos of a helicopter target in Vignette 2 – Mission 12. This mission was a three-round volley of M795 HE projectiles at 19 km in HOB-fuze mode. The RMDs for the three rounds were 2.3 meters, 13.0 meters, and 12.4 meters.

Figure 3-11. Vignette 2 – Mission 12

Effectiveness Analysis

Given that PGK does not meet its reliability requirement with confidence, DOT&E analyzed the relationship between PGK accuracy and reliability and the Army's required effectiveness (probability of damaging effects). As long as PGK accuracy is not more than 40 meters CEP, the overall effectiveness of the PGK-fuzed projectiles meets the user's intent even if the reliability is as low as 86 percent. PGK, with a demonstrated upper bound on accuracy of

20.9 meters and a lower bound on reliability of 88.7 percent, produces required lethal effects on target.

DOT&E used the Joint Munitions Effectiveness Manual Weaponeering System, version 2.1, as the model for examining PGK effectiveness. The analysis was based on three threat targets: a Straight Flush fire control radar used for SA-6 and SA-11 surface-to-air missiles; a GAZ-66 off-road military truck used for land transport and as a communications van; and a 2S19 Self-Propelled 152 mm Howitzer. These targets are shown, from left to right, in Figure 3-12.

Figure 3-12. Threats Used for PGK Effectiveness Analysis

For each of the threat targets, the following factors and levels were used as input to each model run:

- 2 Projectiles: M795 HE and M549A1 RAP
- 2 Target Ranges: 15 and 20 km for M795 HE; 20 and 25 km for the M549A1 RAP
- 2 Mission Lengths: a single 3-round volley and two 3-round volleys
- 2 Fuze Modes: Point Detonating (PD) and Height-of-Burst (HOB)
- 4 Accuracy Levels: 50, 40, 30, and 20 meters CEP
- 4 Reliability Levels: 92, 90, 88, and 86 percent.

Probability of damaging effects was computed for each threat, projectile, range, mission length, fuze mode, accuracy and reliability combination. The results are presented with respect to the Army's requirements for accuracy (50 meters CEP) and reliability (92 percent) as a representation of the user's desired effectiveness.

All model results are presented as a ratio of the model results to the Army's requirement. Ratios greater than or equal to one mean that the probability of damaging effects meets or exceeds the user's desired results for the modeled conditions. Ratios less than one mean that the probability of damaging effects does not meet the user's desired results for the modeled conditions.

Tables 3-5 to 3-7 show the results of the analysis. The tables reflect combined results within mission length and fuze mode, as these factors had no effect on the results. The demonstrated combined results for M795 HE and M549A1 RAP PGK reliability and accuracy are indicated by the “x” in the table. The demonstrated results for individual projectiles are indicated by the triangles.[21]

Table 3-5. Effectiveness Analysis Results for Straight Flush Radar

M795 HE

Range: 15 km — Reliability

Accuracy	0.92	0.90	0.88	0.86
50 m	1	0.98	0.98	0.95
40 m	1.21	1.20	1.18	1.16
30 m	1.47	1.45	1.44	1.41
20 m	1.78	1.76	1.75	1.74

Range: 20 km — Reliability

Accuracy	0.92	0.9	0.88	0.86
50 m	1	0.98	0.97	0.96
40 m	1.20	1.18	1.17	1.16
30 m	1.45	1.43	1.42	1.40
20 m	1.75	1.73	1.71	1.70

M549A1 RAP

Range: 20 km — Reliability

Accuracy	0.92	0.90	0.88	0.86
50 m	1	0.98	0.97	0.96
40 m	1.22	1.20	1.19	1.18
30 m	1.49	1.48	1.46	1.44
20 m	1.79	1.77	1.77	1.75

Range: 25 km — Reliability

Accuracy	0.92	0.9	0.88	0.86
50 m	1	0.98	0.97	0.96
40 m	1.20	1.19	1.17	1.16
30 m	1.44	1.43	1.42	1.41
20 m	1.71	1.70	1.69	1.68

User's "Requirements"
≥ User's "Requirements"
< User's "Requirements"

x = Current results - IOT+ LATs 1,2,3 (UCB on CEP of 20.9 m/LCB on reliability of 89.8%)
△ = (M795 HE – UCB on CEP =21.9 / LCB on Reliability = 92%; M549A1 RAP – UCB on CEP = 21.4 / LCB on Reliability = 85%)

Table 3-6. Effectiveness Analysis Results for GAZ-66

M795 HE

Range: 15 km — Reliability

Accuracy	0.92	0.90	0.88	0.86
50 m	1	0.99	0.94	0.94
40 m	1.34	1.30	1.27	1.25
30 m	1.81	1.79	1.78	1.72
20 m	2.61	2.60	2.54	2.49

Range: 20 km — Reliability

Accuracy	0.92	0.9	0.88	0.86
50 m	1	0.99	0.96	0.95
40 m	1.34	1.30	1.29	1.27
30 m	1.82	1.76	1.75	1.75
20 m	2.62	2.56	2.57	2.48

M549A1 RAP

Range: 20 km — Reliability

Accuracy	0.92	0.90	0.88	0.86
50 m	1	1	0.99	0.96
40 m	1.37	1.37	1.33	1.31
30 m	1.95	1.94	1.90	1.88
20 m	2.89	2.87	2.83	2.79

Range: 25 km — Reliability

Accuracy	0.92	0.9	0.88	0.86
50 m	1	0.98	0.95	0.94
40 m	1.36	1.33	1.30	1.28
30 m	1.90	1.86	1.84	1.80
20 m	2.73	2.76	2.57	2.64

User's "Requirements"
≥ User's "Requirements"
< User's "Requirements"

x = Current results - IOT+ LATs 1,2,3 (UCB on CEP of 20.9 m/LCB on reliability of 89.8%)
△ = (M795 HE – UCB on CEP =21.9 / LCB on Reliability = 92%; M549A1 RAP – UCB on CEP = 21.4 / LCB on Reliability = 85%)

21 Demonstrated results are presented at the upper one-sided confidence bound (UCB) on CEP and the lower bound of the 80 percent confidence interval (LCB) for reliability.

Table 3-7. Effectiveness Analysis Results for 2S19 Self-Propelled Howitzer

M795 HE

Range: 15 km

Accuracy	Reliability 0.92	0.9	0.88	0.86
50 m	1	1	1	1
40 m	1.5	1.5	1.5	1.5
30 m	2.75	2.75	2.75	2.75
20 m	5.38	5.38	5.25	5.25

Range: 20 km

Accuracy	Reliability 0.92	0.9	0.88	0.86
50 m	1	1	1	1
40 m	1.75	1.75	1.75	1.75
30 m	2.92	2.92	2.92	2.75
20 m	6.09	6.09	6.09	6.09

M549A1 RAP

Range: 20 km

Accuracy	Reliability 0.92	0.9	0.88	0.86
50 m	1	0.875	0.875	0.875
40 m	1.5	1.5	1.5	1.5
30 m	2.63	2.5	2.5	2.38
20m	5.38	5.25	5.25	5.25

Range: 25 km

Accuracy	Reliability 0.92	0.9	0.88	0.86
50 m	1	0.875	0.875	0.875
40 m	1.5	1.5	1.38	1.38
30 m	2.5	2.5	2.5	2.5
20m	5.25	5.25	5	4.88

User's "Requirements"
≥ User's "Requirements"
< User's "Requirements"

✖ = *Current results - IOT+ LATs 1,2,3 (UCB on CEP of 20.9 m/LCB on reliability of 89.8%)*
▲ = *(M795 HE – UCB on CEP =21.9 / LCB on Reliability = 92%; M549A1 RAP – UCB on CEP = 21.4 / LCB on Reliability = 85%)*

The model results show that PGK's demonstrated accuracy (20.9 meters LCB) relative to the requirement (50 meters) more than compensates for not meeting the reliability requirement. When effects of reduced reliability are examined at the 50 meter CEP requirement, the probability of damaging effects is less than required, as indicated by red in the table. In the case of the M795 HE/Self Propelled Howitzer condition, the model would suggest that decreased reliability has no impact on damaging effects. Hard targets require better accuracy, so at 50 meters the M795 HE reductions in reliability cannot further reduce already poor performance. As long as the demonstrated PGK accuracy is not more than 40 meters CEP, the overall effectiveness of the PGK-fuzed projectiles meets the user's intent of required damage even if the reliability is as low as 86 percent.

Using the demonstrated PGK accuracy and reliability, the model predicts that PGK-fuzed projectiles would produce 1.7 times the damaging effects on a Straight Flush Radar, 2.6 times the effects for the GAZ-66, and 5.4 times the effect for the 2S19 Self-Propelled Howitzer compared to PGK-fuzed projectiles performing at the required reliability and accuracy. Straight Flush Radar, GAZ-66, and 2S19 Self-Propelled Howitzer, represent targets of increasing difficulty for artillery. Predicted damaging effects increase with increasing target difficulty for improved accuracy, because for softer targets effects are not improved upon by decreased CEP.

Other Effectiveness Factors

Fire Support Command, Control, Communications, and Computer (FSC4) Systems

The 2014 integrated Excalibur IOT&E and PGK LUT validated the capability of the Army's FSC4 systems to process Precision-Guided Munition (PGM) missions and the compatibility of PGK with all elements of the fire support system in an operational environment.

Combat Observation Lasing Teams (COLT) used the forward observer system to initiate HE, PGK, and Excalibur fire missions. The fire support element and battalion FDC processed 139 of 141 fire missions. Platoon FDCs processed all Excalibur and PGK live fire missions. FSC4 systems filtered targeting data from less precise targeting systems and accepted targeting data from targeting systems with a Target Location Error (TLE) of no greater than 15 meters. AFATDS automated the tactical selection of weapons, munitions, and method of fire, and calculated the PGM technical firing data.

Targeting

Forward observers in the integrated Excalibur IOT&E and PGK LUT were equipped with the M1200 Armored Knight Fire Support Vehicles (FSV) and used the Fire Support Sensor System (FS3) laser rangefinders and software for locating the mobile personnel and light materiel targets. In a side-by-side excursion conducted during forward observer exercises, COLTs used a LLDR-2H rangefinder to locate the same targets as the FS3s. Observer-to-target distances were between 1 kilometer and 2.3 kilometers.

Table 3-5 shows TLE for missions initiated by COLTs using FS3s and the LLDR-2H. During this test, COLTs located 45 of 46 targets (98 percent) in their first attempt with FS3s. The average TLE for targets using FS3 was 5.7 meters. Ninety-two percent (47 of 51) of TLEs for the personnel and vehicle targets located with FS3s were less than 10 meters.

Table 3-5. Excalibur-PGK OT Target Location Errors

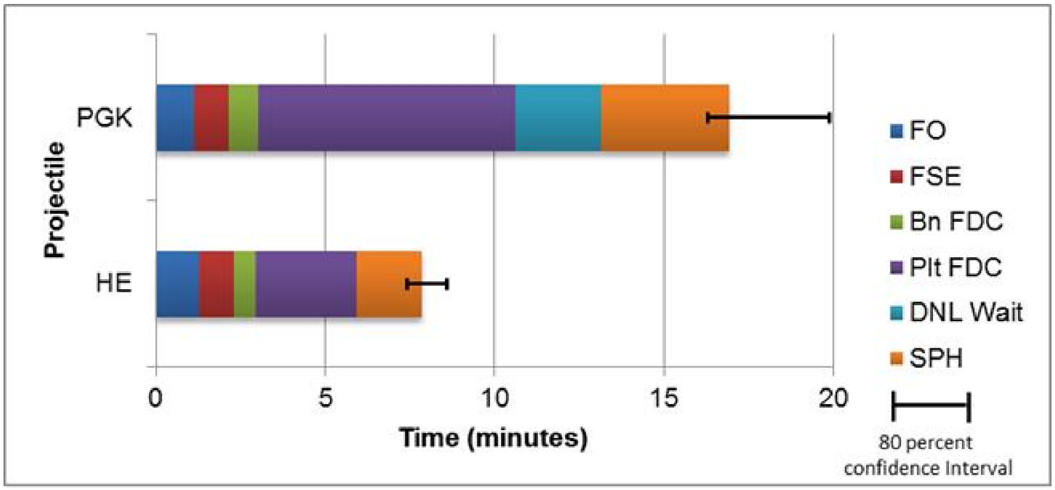
Acquisition System	Mean	80% Confidence Interval	Minimum	Maximum
FS3	5.7 meters	5.1 – 6.3 meters	0.8 meters	15.8 meters
LLDR-2H	16.8 meters	13.0 – 23.3 meters	1.3 meters	117.6 meters

In the LLDR-excursion, COLTs located 33 of 46 targets (72 percent) with TLEs less than 15 meters in their first attempt. The average TLE for the IOT&E targets located using the LLDR-2H was 16.8 meters.

PGK Mission Timelines

PGK mission timelines for individual point targets when compared to standard high-explosive (HE) mission timelines are 2.1 times longer. PGK missions had an average completion time of 16.9 minutes while standard HE missions had an 8-minute average completion time. Increased PGK mission times are an acceptable consequence of mission planning and coordination requirements when PGMs are employed. The processing of these missions includes collateral damage estimation and risk assessments and higher level mission coordination and approval.

The Army has not established timeliness standards for PGK fire missions. For this report, DOT&E used data collected during the 2014 integrated Excalibur IOT&E and PGK LUT to compare LUT PGK and unguided HE fire mission timelines. Figure 3-12 shows the average times for LUT PGK fire missions (16.9 minutes) versus average times for LUT missions with unguided HE projectiles (8.0 minutes). Mission timelines start with identification of the target by the forward observer, and end when the last howitzer participating in the fire mission fires its first round. Sections of the timeline bar show average mission processing times for the forward observers, command and control nodes, and the self-propelled howitzers.



Bn – battalion; FO – forward observer; FSE – fire support element; FDC – fire direction center; Plt – platoon; DNL – do-not-load; SPH – self-propelled howitzer

Figure 3-12. PGK LUT Fire Mission Times

The greatest difference between times for PGK and HE fire missions were in the platoon FDCs, where times were 2.5 times longer than for platoon FDC HE times. In PGK fire missions, the platoon FDC calculated technical firing data, a task done by the howitzers during standard HE fire missions. Because PGK-fuzed projectiles can lose initialization data after 7 minutes, platoon FDCs started PGK missions with do-not-load (DNL) fire orders for the howitzers. After all howitzers had traversed to the appropriate firing azimuth, prepared projectiles for receipt of mission data, and reported they were ready to proceed, FDCs continued the missions with at-my-command fire orders authorizing howitzer crews to initialize and load projectiles. Once all howitzer sections were ready, observers transmitted the order to fire the projectiles. The average platoon FDC time for PGK missions includes time for the forward observers and higher headquarters nodes to respond after the howitzers reported they were ready.

During the LUT, the average howitzer section waited 2.5 minutes from the time it reported ready in response to the DNL fire order until it received the at-my-command order to proceed (shown as “DNL Wait” in Figure 3-12). With the extra time involved in the DNL portion of the fire mission, average howitzer response times for PGK missions were 2.1 times longer than for standard HE fire missions.

Quadrant Elevation (QE)

There is an identified performance issue when firing PGK in a high angle or QE (>900 mils) environment. Because of the lighter air density when the PGK-fuzed projectile approaches apogee and begins the downward flight path, there is limited maneuver authority in the design of the PGK guidance module to make necessary corrections to the flight path. For the M549A1 HE RAP, the TTP states that PGK-fuzed M549A1 HE RAP should not be fired at a QE above 936 mils, as degraded accuracy can be expected. PGK-fuzed M795 HE projectiles should not be fired at a QE above 1,200 mils as identified in the PGK TTP, as degraded accuracy can be expected. PGK can service the full range of targets from 8 – 28 kilometers by a combination of projectiles, charges, and lower QEs under standard meteorological conditions.

Height-of-Burst (HOB)

PGK has an effective HOB capability. In the IOT&E, all 19 PGK fuzes that were set for HOB mode functioned.[22] The average detonation height above the ground for the IOT&E projectiles was 11.1 meters, with a maximum of 14.0 meters and a minimum of 8.7 meters. All IOT&E HOBs were within the required HOB range (95 percent between 6 – 14 meters, maximum air burst 20 meters). The Army measured detonation height with test instrumentation during IOT&E.

During the three Lot Acceptance Tests (LATs), 62 of 64 PGK fuzes that were set for HOB mode functioned.[23] The average HOB was 8.7 meters with a maximum of 13 meters. There were nine HOBs recorded that were less than 6 meters above the ground. During the LATs, HOB measurement was based on a triangulation of data collected by three offside observers.

Figure 3-13 shows the distribution of all 81 HOBs observed during the four tests. The overall mean HOB was 9.3 meters. A total of 89 percent of the observed HOBs were in the desired range of 6 – 14 meters, less than the 95 percent required. All of the HOBs out of desired range were low and functioned prior to ground impact. PGK has an effective HOB capability.

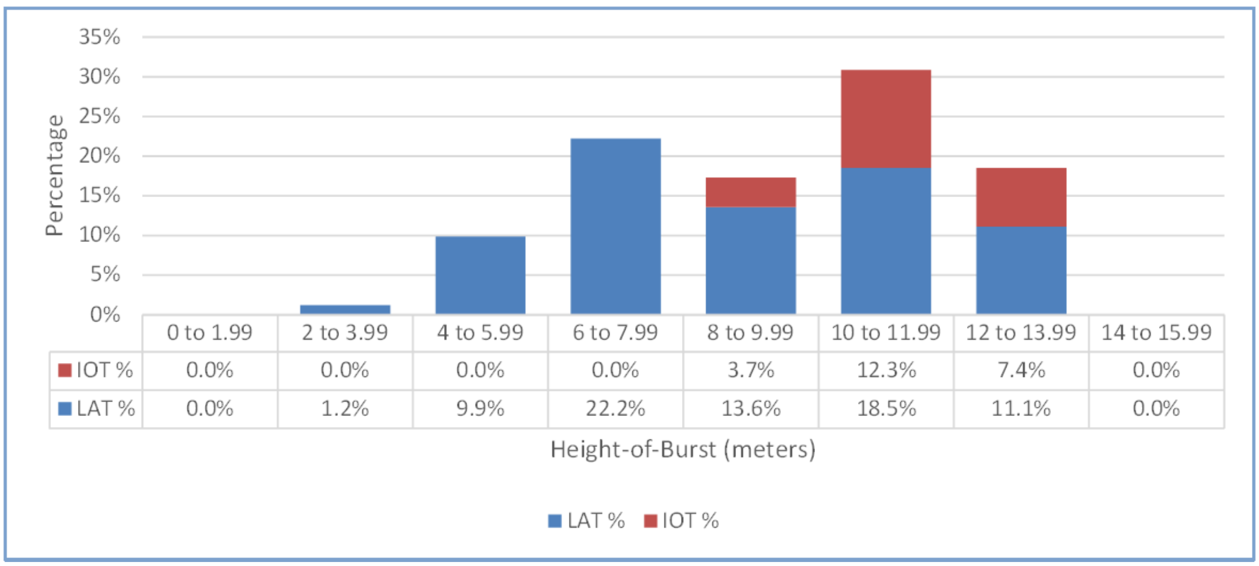


Figure 3-13. PGK Heights-of-Burst in IOT&E and LATs

22 This does not include the PGK-fuzed projectiles fired but excluded from the analyses.

23 The two HOB reliability failures are discussed in Section Four.

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Section Four
Operational Suitability

The Precision Guidance Kit (PGK) fuze is operationally suitable. During Initial Operational Test and Evaluation (IOT&E) and Lot Acceptance Test (LAT) of production fuzes, Precision Guidance Kit (PGK) demonstrated 92.1 percent reliability with an 80 percent confidence interval of 88.7 – 94.6 percent. PGK can be employed in extreme hot and cold temperatures. Failures of the capacitor in extreme cold environments (less than 0 degrees Fahrenheit) are fixed by changing the procedure to include a double-set of the fuze. The fuze is supportable within the Army's current maintenance, logistics, training, and manpower structures. With fielding of new Muzzle Velocity Management System and Digital Fire Control Systems (DFCS) on M777A2, the Army needs to provide adequate New Equipment Training (NET). PGK software can be upgraded at depot level to preclude obsolescence and to provide for future upgrades. PGK fuzes are safe to handle and employ. The Army should consider instituting a warning in Advanced Field Artillery Tactical Data System (AFATDS) for PGK restrictions and limitations.

Reliability

Based on data from IOT&E and LAT, PGK met its threshold requirement of 92 percent reliability at a point estimate (demonstrated 92.1 percent), but not with confidence. The lower bound of the 80 percent reliability confidence interval is 88.7 percent. PGK is required to achieve at least a threshold level of 92 percent reliability by its Initial Operational Capability (IOC), scheduled for 2QFY16.

A successful PGK is one that sets, survives firing from the howitzer, acquires and maintains a global positioning system (GPS) signal, tracks to and impacts within 150 meters of its aimpoint, and functions in the proper fuze mode – either Point Detonating (PD) or Height-of-Burst (HOB) above the ground.

IOT&E Reliability

In the PGK IOT&E, 37 of 42 fuzes were reliable, yielding a reliability point estimate of 88.1 percent (80 percent confidence interval: 78.9 percent, 94.0 percent). This IOT&E estimate of PGK reliability is below the 92 percent requirement.

If the six PGKs not included in the IOT&E analyses (as discussed in Operational Test Limitations in Section Two) were scored as reliable because they did dud, as designed, when they impacted outside 150 meters from their aimpoints, the PGK IOT&E point estimate would be 89.6 percent, 43 of 48 fired (80 percent confidence interval: 81.5 percent, 94.8 percent). This alternate view of IOT&E reliability provides a marginal difference between reliability point estimates, with both tracking below the user reliability requirement of 92 percent.

If one considers the IOT&E results from an operational perspective, the user did not get expected results, with detonation within 150 meters of the aimpoint, in 10 of the 48 projectiles fired. The operational perspective IOT&E reliability point estimate is 79.2 percent (69.6 percent, 86.6 percent).

IOT&E and LAT Reliability

Each PGK LAT was a sequential test with 42 PGKs available for testing. Acceptance of the lot could be accomplished using as few as 12 PGKs, but in support of reliability testing, the program manager fired 42 PGKs in each of the three LATs. An additional nine firings were added during LAT for Lot 3 to make up for data lost during IOT&E.

The PGKs fired in the IOT&E were produced in LRIP Lot 1, and since there were no changes in configuration from Lot 1 through Lot 3, data from the LATs were considered for inclusion in the PGK reliability assessment.[24] The inclusion of LAT data increased the data available for the reliability assessment from 42 to 177 PGKs.

PGK met its threshold requirement at a point estimate of 92.1 percent (88.7 percent, 94.6 percent), but not with confidence. Table 4-1 summarizes the reliability results from the IOT&E and three LATs.

Table 4-1. Summary of PGK Reliability Results by Test Event

Test	Sample Size	No. Failures	Point Estimate	80% Confidence Interval
IOT&E	42	5	88.1	78.9 – 94.0
LAT 1	42	1	97.6	90.9 – 99.7
LAT 2	42	5	88.1	78.9 – 94.0
LAT 3 + Plus Ups	51	3	94.1	87.3 – 97.8
Total	177	14	92.1	88.7 – 94.6

IOT&E – Initial Operational Test and Evaluation; LAT – Lot Acceptance Test

There is no statistical difference in reliability between PGKs on the M795 HE and the M549A1 HE RAP.[25] On the M795 high-explosive (HE) projectile, PGK reliability was 94.7 percent (90.3 percent, 97.4 percent). On the M549A1 HE Rocket-Assisted Projectiles (RAP), PGK functioned at a lower reliability with a point estimate of 89.0 percent (83.1 percent, 93.2 percent). Table 4-2 provides reliability results by projectile type.

[24] A Generalized Linear Model was fit to the data from the four tests and the data was determined to be combinable, p-value = 0.230.

[25] P-value = 0.175, based on Fisher's Exact Test.

Table 4-2. Summary of PGK Reliability Results for Projectile Type

Projectile Type	Sample Size	No. Failures	Point Estimate	80% Confidence Interval
M795 HE	95	5	94.7	90.3 – 97.4
M549A1 RAP	82	9	89.0	83.1 – 93.2

Not Significantly Different

HE – High-Explosive; RAP – Rocket-Assisted Projectile

During the conduct of the four tests, there were 14 observed failures. Each of the observed failure modes has an operational impact on the user's intended artillery mission effects. Six definitive failure modes accounted for 11 of the 14 failures. The other three failures were duds that occurred during the IOT&E on PGKs for which no telemetry data were collected. Without telemetry, the definitive causes of these duds cannot be determined. Two of the three IOT&E duds impacted within 150 meters (60.4 and 110.4 meters) of the projectile's aimpoint and one impacted at 182 meters from its aimpoint. Table 4-3 shows the failure mode occurrences by test event.

Table 4-3. Observed Failure Modes by Test Event

Test	Observed Failure Modes						
	Loss of GPS Signal	Loss of Internal Power	Short-Range Round	No HOB – Functioned in PD	Dud – Guided (Miss < 150m)	Dud – Insufficient Guidance (Miss > 150m)	Dud – Unknown Cause
IOT&E	2						3
LAT 1	1						
LAT 2	1	1	2	1			
LAT 3		1			1	1	
Total	4	2	2	1	1	1	3

IOT&E – Initial Operational Test and Evaluation; LAT – Lot Acceptance Test; HOB – Height-of-Burst; PD – Point Detonating

For both the Loss of Internal Power and Loss of GPS Signal failure modes, the fuze does not acquire (no power) or loses the satellite signal (loss of GPS), precluding any further guidance capability and resulting in the PGK-fuzed projectile flying a ballistic trajectory and impacting the ground without arming or functioning. The projectiles, whether they impact outside 150 meters or inside 150 meters, do not detonate and provide no lethal effects in the target area.

The Short-Range Round failure mode is when the round impacts significantly short of their intended target. This failure mode is a critical safety hazard if impact is at less than 90 percent of the intended range. The impacts are at a great distance, in these two cases, 1,818 and 3,512 meters, short of the intended aimpoint. Since the impact is more than 150 meters from the aimpoint, the round does not detonate. These failures increase the risk to ground forces between the howitzer and the intended impact area, the risk of collateral damage to non-combatants in the area, and the risk of unexploded ordnance that an enemy might use for an improvised explosive device. Several corrective actions have been incorporated into PGK over the last two years of development, which have reduced, but not eliminated the Short-Range Round occurrences. The program should continue to pursue its failure investigation and examine potential corrective actions to eliminate this safety hazard to Soldiers and non-combatants.

In the No Height-of-Burst (HOB) – Functioned in Point Detonating (PD) failure mode, the fuze does not detonate in the user's intended mode. The round provides some lethal effects around the impact area, but not the effects that were intended with the detonation at 10 meters above the ground.

The Dud – Guided (Miss < 150 meters) failure mode has been prevalent throughout the development program for PGK. PGK guides throughout the flight and the proper firing sequence is provided to the fuze's safe and arm device, but the round does not detonate.

The Dud – Insufficient Guidance (Miss > 150 meters) failure results from canard control issues that limit the ability of PGK to guide during flight. The round impacts more than 150 meters from the aimpoint and does not detonate.

PGK in Extreme Climate Conditions

PGK has been tested at extreme temperatures and exposed to Paladin Tactical Vibration environmental conditioning in the majority of all developmental testing. In addition, as part of the sequential environmental test for performance, PGK was tested at the Cold Regions Test Center in the natural cold environment of Alaska in January 2015.

Hot and Cold Conditioned Testing During LATs

A total of 94 of the 135 LAT PGKs (42 in LAT 1, and 26 in each of LAT 2 and LAT 3) underwent Paladin Tactical Vibration conditioning, which also subjected the fuzes to conditioning at extreme temperature, one-half at -25 degrees Fahrenheit and one-half at +145 degrees Fahrenheit.

Seventy-two PGK fuzes fired during LATs 1, 2, and 3 were chamber conditioned to extreme temperatures consistent with the operating temperature ranges of -25 degrees Fahrenheit to +145 degrees Fahrenheit immediately prior to firing. A total of 36 PGKs were fired at hot (+145 degrees Fahrenheit) temperatures and 36 were fired at cold (-25 degrees Fahrenheit) temperatures. At hot, 34 of 36 PGK fuzes (94.4 percent) functioned. At cold, 35 of 36 PGK fuzes (97.2 percent) functioned. Of the remaining 63 PGK fuzes tested during LAT that were not subjected to environmental conditioning for firing, 57 of 63 PGK fuzes (90.4 percent) functioned. The reliabilities of the three sets (cold, hot, and ambient) of PGKs fired in the LATs were not different indicating that the cold and hot conditioning did not affect reliability.[26]

[26] P-value = 0.437, based on Fisher's Exact test.

Environmental conditioning does not affect the accuracy of PGK. The observed median radial miss distance (RMD) for the 36 hot conditioned fuzes that functioned was 10 meters. The observed median RMD for the 35 cold conditioned fuzes that functioned was 9 meters. The overall observed median RMD for the 56 fuzes not conditioned was 8 meters. The median RMDs of the three sets of environmental data fired during the LATs are not different indicating that the cold and hot conditioning did not affect accuracy.[27]

Natural Conditions (Cold Regions Test Center)

For the 18 PGKs that functioned during the Cold Regions test, the median RMD was 30.4 meters. This median is greater than the overall median of 10.0 meters demonstrated in LAT and IOT&E. It meets the user accuracy requirement of 50 meters. A total of 18 of the 21 PGKs functioned during the test. The point estimate of reliability in this environment is 85.7 percent (70.8 percent, 94.6 percent). This is consistent with reliability results from IOT&E and LAT.[28]

A total of 21 PGKs were taken to the Cold Regions Test Center and fired as the cold portion of the sequential environmental test for performance. These fuzes underwent a 14-day cold soak conditioning at -60 degrees Fahrenheit and Paladin Tactical Vibration conditioning at -25 degrees Fahrenheit. The configuration tested differed from production as it did not include a software change introduced after this test to fix Loss of Internal Power failure mode.

The Army Test and Evaluation Command (ATEC) fired 10 PGKs on M549A1 HE RAP and 11 PGKs on M795 HE projectiles. All firing was done from an M777A2 Howitzer (Figure 4-1). The three failures were: two Loss of Internal Power failures and a Dud – Guided (Miss < 150 meters).

Figure 4-1. PGK Testing at Cold Regions Test Center on M777A2 Howitzer

27 P-value = 0.111, based on Mood's Median test.

28 P-value = 0.52, based on Fisher's Exact Test.

The two Loss of Internal Power failures occurred on the second day of testing, during extreme cold temperatures (-25 degrees Fahrenheit). Because of the extreme temperature, the on-site assessment was that the capacitor in PGK, which gets its power from the Enhanced Portable Inductive Artillery Fuze Setter (EPIAFS) during the setting process, was not charged and not able to retain the mission firing data until firing. Subsequent to these two firings, fuze-setting procedures were amended to double-set the PGKs to charge the capacitor. No further problem was seen during the remainder of the test. The Army should incorporate the double-set procedure in cold environments into the PGK TTPs.

The third failure, a Dud – Guided (Miss < 150 meters), was not attributed to the cold weather environment.

Logistics Supportability

The logistics supportability for PGK is described in the Life Cycle Sustainment Plan, dated March 26, 2012. This plan is being updated prior to the planned Full-Rate Production (FRP) decision.

Maintenance Concept

The support strategy for PGK uses the Army's standard two-level system of field and sustainment maintenance. PGKs are stored and maintained in sealed barrier bags and protected by internal foam dunnage in a standard ammunition container. Three PGKs are in each ammunition container as shown in Figure 4-2. There are no expendable supplies or repair parts required to support PGK throughout its life. PGK does not require any scheduled maintenance. Field maintenance consists of care, preservation, and cleaning of the PGK ammunition container. PGKs will be issued to artillery units through standard ammunition supply procedures and, if not fired, will be returned through normal ammunition turn-in procedures.

Figure 4-2. PGK Ammunition Container and PGK

Software Upgradability

PGK maintains an external reprogramming capability through a maintenance port connector within the fuze. The capability exists to upgrade the Operational Flight Software and GPS software, both of which have been implemented in production engineering change proposals without exhibiting subsystem interoperability issues. The operating and support budget includes the resources to perform periodic software updates. This capability addresses the user's requirement that the software be upgradeable at depot level.

Safety

PGK is safe to handle in its ammunition containers during storage and transport as demonstrated in operational testing developmental sequential environmental test for safety. The packaged fuzes were exposed to extreme temperatures (cold (-60 degrees Fahrenheit) and hot (+160 degrees Fahrenheit)) and were then exposed to loose cargo (rough handling), 2.1-meter drop, and tactical vibration testing. Following these tests, PGKs were fuzed to both M795 HE projectiles and M549A1 HE RAP and fired with overpressure propellant charges. No safety-related problems surfaced during any of these tests that would impact the handling, storage, transport, firing, or disposal of PGKs.

Safety Confirmations

ATEC issued safety confirmations on July 14, 2015, to cover PGK FRP with guidance, navigation, and control software version 3.1 build 1 and GPS system software version 3.14 on August 6, 2015. The Safety Confirmations were to cover PGK FRP with the new GPS software version 3.15. GPS software version 3.15 was loaded onto the remainder of LRIP Lot 3 after LAT 3 was completed. Both Safety Confirmations identified the hazard associated with the critical Short-Range Rounds. As corrective actions have not been successful in eliminating this hazard, the overall hazard classification for PGK is a medium risk (catastrophic – improbable).

Another issue addressed in the Safety Confirmation is the occurrence of undesired projectile detonations upon ground impact. The normal result of an unreliable PGK is that the projectile will impact as a dud. This situation is the same as that for any conventional-fuzed projectile whose fuze fails. During PGK's developmental testing, there were 13 occurrences in which PGK either failed to acquire or lost its GPS signal. The onboard telemetry confirmed that PGK software did not send an arming signal to the safe and arm module. The projectile exploded following impact with the ground. The detonations occurred below ground level and at less than the full explosive capability of the round. The possible causes of the detonations are the shockwave created on impact, the projectile's explosive fill, or the functioning of PGK's fuze booster upon impact. These incidents occurred regardless of the RMD from the intended target relative to the safe arm distance of 150 meters. The Safety Confirmation addressed these occurrences as a nominal risk to personnel. This risk is the same for both PGK-fuzed and conventionally-fuzed projectiles. Field commanders should be reminded of this risk with the fielding of PGK.

Human Systems Integration

PGK has no outstanding Human Systems Integration issues. Field artillery units have fired PGK in two operational tests and Urgent Materiel Release (UMR) PGKs with success in combat theaters.

Manpower and Personnel

The employment of PGK requires no additional manpower within employing field artillery units. Soldiers processing and firing PGK missions require no additional skills to execute a PGK mission.

Human Factors Engineering

PGK is handled by the field artillery unit in the same manner as any of the conventional inductive artillery fuzes, such as the M762, M782, and the M982. PGK is attached to the projectile using PGK fuze wrench as shown in Figure 4-3. The crews set PGK with no problems noted. The crew then places the PGK-fuzed projectile onto the howitzer's loading tray. The loading of the PGK-fuzed projectile onto the howitzer's loading tray must be accomplished with care so as not to damage the canards on the fuze. The Soldiers recognized this and stated in their comments that care must be taken. No problems have been noted in this area.

Figure 4-3. Soldier Assembling PGK to Projectile with PGK Fuze Wrench

Handwear Compatibility

During the Limited User Test (LUT) with the UMR PGK, Soldiers from the test unit conducted an excursion to install PGK on a projectile, set PGK, and remove the canard cover while wearing field gloves, nuclear, biological, and chemical (NBC) protective gloves, masks, and extreme cold weather mittens. The lowest difficulty was reported while wearing field hand-wear where 19 percent (8 of 42 Soldiers) reported re-installing PGK covers to be difficult and 21 percent (7 of 34 Soldiers) reported removing them to be difficult. The highest difficulty was reported while wearing extreme cold weather mittens. Thirty-three percent (10 of 30 Soldiers) and 37 percent (11 of 30 Soldiers) reported that it was difficult to remove and reinstall the PGK cover. DOT&E observed no problems in the various steps of the excursion. In addition, the unit conducted two of the missions in the LUT while in modified Mission Oriented Protective Posture (MOPP) 4 (wearing NBC gloves and masks). There were no indications of problems in either mission. The questionnaire results identified no deficiencies in operator performance in MOPP 4.

Training

The IOT&E test unit was an M777A2-equipped unit from Fort Drum, New York. The Army's PGK NET team from the Fires Center of Excellence conducted pre-test PGK NET.

The NET was adequate for PGK. The PGK NET was rated by the 24 cannoneers trained as positive for 86 percent of the questions asked relative to training. The seven automated tactical data system specialists and leaders rated the training as adequate or better for 80 percent of the questions asked on training.

The NET was not adequate for the DFCS software. The IOT&E test unit was proficient with the Army's howitzers and DFCS (Version 3.1.2), but had never fired a round with the USMC's howitzers or DFCS (Version 4.1.0).[29] The program manager – Towed Artillery Systems NET team conducted training for the unit on the USMC howitzers and DFCS. The NET team also provided training on the Advanced Field Artillery Tactical Data System (AFATDS) and its interface with the USMC DFCS. The training on the M777A2 was insufficient to eliminate firing solution problems with the IOT&E missions.[30]

The Army needs to develop a better, more effective NET with the fielding of the Integrated Muzzle Velocity Management System and updated DFCS software to Army units.

Tactics, Techniques, and Procedures (TTPs)

The published PGK TTPs (Special Text No. 3-09.53) are complete and easy to understand. They provide a good description of PGK, when to use it, the impact of various Target Location Errors (TLEs), the use of forward observer systems, how the fire support element handles PGK through use of AFATDS, etc. It describes techniques for recognizing jammed/spoofed environments in which PGK should not be employed. The TTPs describe PGK employment restrictions and limitations.

- PGK restrictions:
  - PGK-fuzed projectiles will not be fired with M231, charge 1 propellant

[29] The fielding of the Integrated Muzzle Velocity Management System and updated DFCS software to Army M777A2 units began in September 2015. With the approval of DOT&E, the test unit did not bring its own howitzers to Yuma Test Center (YTC), but was instead issued USMC M777A2 Howitzers already at YTC for use in the test.

[30] The first five missions of the IOT&E, two with conventionally-fuzed HE projectiles and three with PGK-fuzed projectiles, were fired with improper firing solutions, which were attributable to inadequate muzzle velocity management.

- PGK limitations:
  - M795 HE PGK-fuzed projectiles should not be fired at a quadrant elevation (QE) above 1,200 mils, as degraded accuracy can be expected
  - M549A1 HE RAP PGK-fuzed projectiles should not be fired at a QE above 936 mils, as degraded accuracy can be expected

Soldiers firing PGKs must be familiar with the restrictions and limitations, as there are no safety or alert messages provided by AFATDS when the firing solution does not conform to the proper combinations for accurate firing results. The Army should consider instituting a warning in AFATDS for PGK restrictions and limitations.

Section Five
Survivability

Performance of Precision Guidance Kit (PGK)-fuzed projectiles in a countermeasure environment can be found in the classified annex of this report. Cybersecurity assessments identified vulnerabilities such that PGK may be susceptible to insider and nearsider cybersecurity threats with physical access. Cybersecurity testing and results are reported in a classified annex to this report. PGK has demonstrated in testing that PGK-fuzed projectiles are not more detectable in flight than conventional-fuzed projectiles, so PGK does not increase the susceptibility of a field artillery unit to detection and counterfire.

GPS

Performance of PGK-fuzed projectiles can be found in the classified annex of this report. Performance of PGK-fuzed projectiles may be degraded or rendered ineffective by GPS jamming or spoofing.

Cybersecurity

Cybersecurity assessments identified vulnerabilities revealing that PGK may be susceptible to an insider and nearsider cyber threats with physical access. Vulnerabilities identified during system-of-systems cybersecurity testing can affect the operational employment of PGK. Cybersecurity testing showed a need for further testing of the fire support command and control network. Cybersecurity testing and results are reported in a classified annex to this report.

Electromagnetic Environmental Effects (E3)

PGK was tested at external RF EME frequencies and power levels. Technical testing has shown that PGK is survivable, safe, and meets mission requirements when exposed to the full range of the other required E3.

Nuclear, Biological, and Chemical (NBC)

Contamination/Decontamination

PGKs in ammunition cans can survive contamination and decontamination in an NBC environment and remain operational. The ammunition containers are standard Army ammunition containers. As demonstrated during the PGK Limited User Test (LUT) in 2014, while wearing Mission Oriented Protective Posture (MOPP) gear, Soldiers are capable of completing required tasks with minimal performance degradation.

Detectability

To assess the susceptibility of a unit firing PGK-fuzed projectiles to threat detection and counterfire, ATEC conducted a counter-radar test using Firefinder radars.[31] This evaluation assessed that howitzers firing PGK-fuzed projectiles were no more detectable than howitzers firing conventional-fuzed projectiles, indicating that the employment of PGK did not increase the susceptibility of the Field Artillery unit. Since PGK is operating to its design requirements, fewer rounds will be required to engage targets, reducing opportunities for detection.

Insensitive Munitions (IM)

The current low-rate initial production (LRIP) PGK, as tested in the Lot Acceptance Tests (LATs) and the Initial Operational Test and Evaluation (IOT&E), incorporates a new insensitive munitions (IM) booster. IMs are stable enough to withstand mechanical shocks, fire, and impact by shrapnel without exploding, but remain capable of functioning as intended when initiated by proper means. PGK's IM booster should reduce occurrence of some non-armed impact detonations that occur if booster functioning is the cause of the detonation.

There is no current program to modify existing M795 or M549A1 projectiles to preclude uninitiated explosions, but there is a program to employ IM explosive fill in current and future M795 production. The M795 IM artillery projectiles went into production in fiscal year (FY) 2014 but with the large stockpile of M795 projectiles, the employment of IM-compliant projectiles may be delayed.

[31] Firefinder radars are mobile radar systems for the automatic first-round location of weapons firing projectile rounds (i.e., mortars, artillery, and rockets).

Section Six
Recommendations

The program manager for Precision Guidance Kit (PGK) should:

- Continue to conduct failure mode investigations for Dud, Loss of Global Positioning System (GPS) Signal, and Loss of Internal Power failures and incorporate corrective actions to improve reliability.
- Continue to conduct failure mode investigations for Short-Range Round failures and incorporate corrective actions to improve reliability and safety.
- Update PGK tactics, techniques, and procedures (TTPs) to require Soldiers to double-set the PGK when operating in extreme cold environments (less than 0 degrees Fahrenheit) to ensure proper functioning of the fuze.
- Provide Adequate New Equipment Training (NET) on M777A2 with fielding of new Muzzle Velocity Management System and Digital Fire Control System (DFCS) software to the Army.
- Consider changes in the DFCS and AFATDS to alert the operators of a violation of high quadrant elevation (QE) limitations when processing a PGK fire mission and to require an override to continue processing the mission.
- Address identified cybersecurity vulnerabilities in the system-of-systems required to employ PGK per the classified annex.
- As discussed in the classified annex, perform a Cooperative Vulnerability and Penetration Assessment (CVPA) and an Adversarial Assessment (AA) on the complete Fire Support Architecture, including testing to evaluate the ability of the threat to control agents on compromised mission computers over the Single Channel Ground and Airborne Radio System (SINCGARS) network.